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GENGYM: A Variable Density Stand Table Projection System Calibrated for Mixed Conifer and Ponderosa Pine Stands in the Southwest

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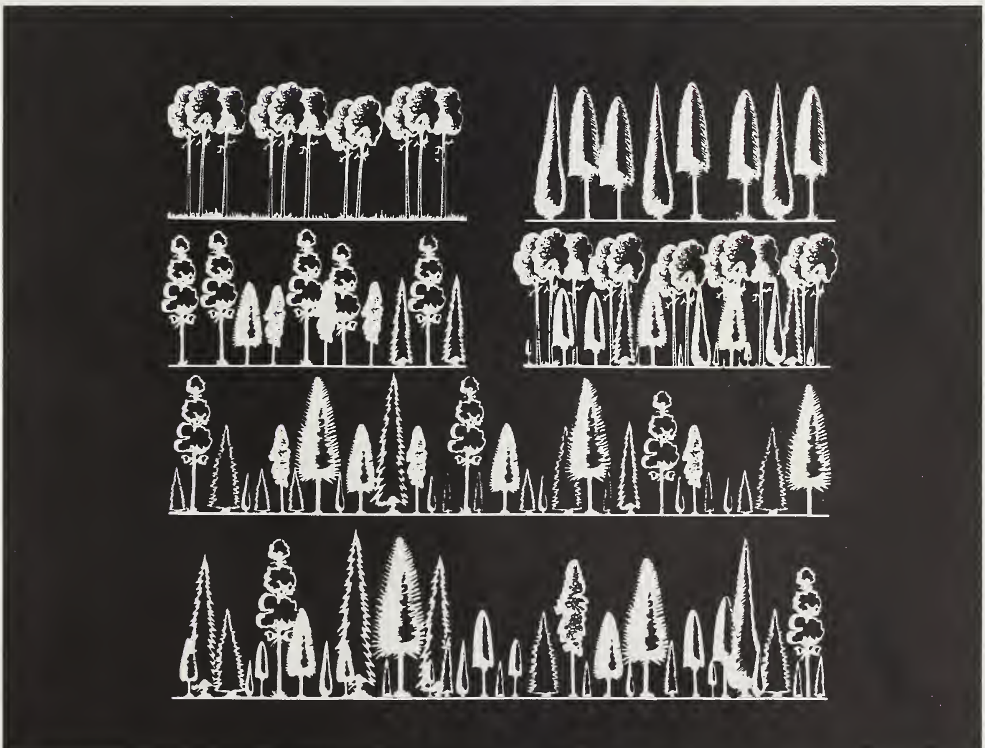

Abstract

A computerized growth and yield model based on a variable density stand table projection system using 1-inch-wide diameter classes has been developed for projecting expected stand conditions in southwestern mixed conifer and ponderosa pine stands, including the effects of dwarf mistletoe. Stand management options include both even-aged and uneven-aged cutting methods.

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Introduction

Stands in the ponderosa pine (*Pinus ponderosa* var. *scopulorum* Engelm.) cover type occupy about 10 million acres in Arizona, New Mexico, and Colorado (Schubert 1974). While much of this area is occupied by essentially pure ponderosa pine stands, a portion of the area may be more accurately described as mixed conifer. Mixed conifer forests occupy about 2.5 million acres in New Mexico, Arizona, and southwestern Colorado on sites more moist than those occupied by pure stands of ponderosa pine (Jones 1974). The common overstory species in the mixed conifer type are Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco), ponderosa pine, white fir (*Abies lasiocarpa* var. *arizonica* (Merriam) Lemm.), Engelmann spruce (*Picea engelmannii* Parry ex Engelm.), aspen (*Populus tremuloides* Michx.), southwestern white pine (*Pinus strobiformis* Engelm.), blue spruce (*Picea pungens* Engelm.), and corkbark fir (*A. lasiocarpa* var. *arizonica* (Merriam) Lemm.). Corkbark fir is replaced by subalpine fir (*A. lasiocarpa* var. *lasiocarpa* (Hook.) Nutt.) in northern Arizona and southwestern Colorado. Mixed conifer forests may contain as few as two or as many as all eight of these species intermixed (Jones 1974). Both southwestern ponderosa pine and mixed conifer forests are being more intensively managed than in the past to enhance timber production and values of other resources. In addition, there is an increasing need to evaluate tradeoffs in favoring other resource values over timber production. Growth and productivity information for southwestern forest types has been limited to simple stand structures and species composition (Edminster 1978, Gottfried 1978, Larson and Minor 1983). As Jones (1974) indicated, growth prediction tools are needed for predicting yields in more complex stand conditions of mixed species and irregular and uneven-aged structures.

Computer program GENGYM (GENeralized Growth and Yield Model) has been developed and calibrated to produce a comprehensive growth and yield model for use in mixed conifer and ponderosa pine stands in the Southwest. The basic structure of the GENGYM model is similar to stand table projection methods available for more than half a century (Meyer 1930, 1935; Wahlenberg 1941). Most stand table projection systems have been limited to projections using recently observed growth rates. These systems are, therefore, only useful for short-term projections and have often been limited to stands of simple species composition. The limitation of using recent growth rates in the projections may be overcome by developing prediction equations for periodic diameter development that include stand density and a measure of the relative competitive position for trees in a particular size class. Two stand table projection models have been previously developed for use in the Southwest, but they are limited to pure stands of ponderosa pine and do not include effects of dwarf mistletoes on growth and mortality relationships (Hann 1980, Larson and Minor 1983).

The basic model units of the GENGYM model are 1-inch-wide diameter classes for each of the species occurring in mixed conifer and ponderosa pine stands. Prediction equations have been developed to estimate 10-year periodic development of diameter, periodic mortality, and height-diameter relationships for each species. Basis model relationships also include effects on specific tree species of these dwarf mistletoe species: on Douglas-fir, *Arceuthobium douglasii* (Engelm.); on ponderosa pine, *A. vaginatum* subsp. *cryptopodum* (Engelm.) Hawksw. and Wiens; and on Engelmann spruce and blue spruce, *A. microcarpum* (Engelm.) Hawksw. and Wiens. On southwestern white pine, dwarf mistletoe (*A. apachecum* Hawksw. and Wiens) did not significantly affect model relationships. Douglas-fir dwarf mistletoe was only rarely observed on the true firs, and its effects are not considered in the model.

The diameter class model structure is a compromise between whole stand models such as RMYLD (Edminster 1978), which provides only stand average and total characteristics, and ASPNORM (Mowrer 1986), which adds diameter distribution information to usual whole stand variables, and individual tree distance-independent models (Stage 1973, Wykoff et al. 1982). While whole stand models are computationally efficient, they are generally applicable only to even-aged stand structures and relatively pure species composition. Individual tree models, on the other hand, can be applied to any age structure and species composition; however, they may be complex from a computational standpoint. The diameter class structure in GENGYM possesses the capability to handle any age structure and species composition, but is designed to be simpler computationally than many individual tree models.

Calibration Data Sets and Plot Measurements

Plots used in the development and initial calibration of GENGYM for southwestern mixed conifers were established as part of a study of effects of dwarf mistletoe on Douglas-fir (Mathiasen et al. 1990). The original study was expanded to include measurements of all species

in the stands selected for sampling. Stands dominated by Douglas-fir in terms of basal area composition were selected for sampling to cover as wide a range of stand conditions as possible. Temporary plots were located in areas of homogeneous stand density, site quality, and species composition. Stand structures included two-storied, multistoried, irregular, and nearly balanced uneven-aged. Both natural and partially cut stands were included in the sample. The partially cut stands could not have been disturbed less than 12 years before sampling to allow for at least 2 years adjustment before 10-year periodic measurements were made. Plot size varied with stand density, with at least 150 live trees present. Average plot area was 0.284 acres (range 0.032–1.023 acres). A total of 237 temporary plots were established for the mixed conifer study on five national forests in the Southwest. Plot distribution by national forest was: Apache-Sitgreaves, 94 plots; Lincoln, 57 plots; Carson, 47 plots; Santa Fe, 27 plots; and Kaibab, 12 plots. Twenty of the plots were selected at random to be used for model verification and were deleted from the calibration data.

To add the ponderosa pine cover type to GENGYM, 150 temporary growth plots were established in pure stands and in stands dominated by ponderosa pine following the same standards used for mixed conifer stands, except that the sample included both even-aged and uneven-aged stand structures. In even-aged stands, plot area was adjusted to include at least 100 live trees. Average plot area was 0.455 acres (range 0.026–2.198 acres). Plot distribution by national forest was as follows: Coconino, 46 plots; San Juan, 30 plots; Kaibab, 23 plots; Apache-Sitgreaves, 21 plots; and Carson, 11 plots. Of the 150 temporary ponderosa pine plots, Douglas-fir was represented in one or more diameter classes in 23 plots, and white fir was represented in 16 plots. In addition to the temporary plots, data from the Taylor Woods levels of growing stock study (Ronco et al. 1985) were included in the calibration data set for ponderosa pine. The Taylor Woods study represents intensive even-aged management and provided 18 plots ranging in size from 0.75 to 1.24 acres, covering two 10-year growth periods. The Taylor Woods plots are also located within the Coconino National Forest. Because of past stand management practices, the ponderosa pine data set included a much higher proportion of managed stands than the mixed conifer set. Twenty-six of the ponderosa pine plots were selected at random for model verification; these were deleted from the calibration data.

Once plot boundaries were surveyed, diameter outside bark (d.b.h.) was measured to the nearest 0.1 inch at breast height (b.h.) on all trees. Ten-year periodic radial wood growth was measured from increment cores taken at b.h. on what appeared to be an average diameter for each tree. Past d.b.h. outside bark was computed using relationships for Engelmann spruce (Myers and Alexander 1972) for all spruces, Douglas-fir, and true firs. Ponderosa pine past d.b.h. relationships (Myers 1967) were used for all pines and other conifers. Relationships for aspen (Mowrer and Edminster 1985) were used for all hardwoods. Total tree heights and height to compacted live crown were measured to the nearest foot. Ages were sampled across the range of diameters from increment cores at b.h. Periodic mortality was estimated based on condition of dead trees. While it was generally easy to determine if trees had died within the last 5 years, determining 10-year mortality was often more difficult. In mixed conifer plots, sample dominant Douglas-firs were measured for b.h., age, and total height for the determination of site index (Edminster et al. 1991). Where suitable trees of other species were also available, additional site trees were sampled, but Douglas-fir was the only species available for site index determination on all mixed conifer plots. Seedling presence and height development were measured on at least two 6-foot-wide transects across each plot. In ponderosa pine plots, sample dominant ponderosa pines were measured for determination of site index (Minor 1964). Site index was not determined for other species when present. Measurements of seedling presence only were included on a 0.01-acre subplot in the center of the ponderosa pine plots.

Other species were occasionally encountered in field sampling; these were grouped into other softwoods and other hardwoods categories in the mixed conifer data set. Other softwoods included bristlecone pine (*Pinus aristata* Engelm.), pinyon (*P. edulis* Engelm.), and juniper (*Juniperus* spp.). Other hardwoods included Gambel oak (*Quercus gambelii* Nutt.), New Mexico locust (*Robinia neomexicana* Gray), and willow (*Salix* spp.). The reliability of relationships developed for these species is probably quite low because of the small sample sizes. In the ponderosa pine data set, the d.b.h. of species other than ponderosa pine, Douglas-fir, and white fir were measured for computation of stand basal area, but other growth, height, and mortality data were not collected.

Data Analysis and Model Relationships

Determination of Basic Model Unit

Before regression analysis to develop needed relationships could begin, a decision on a suitable diameter class width was needed. Diameter class widths of 1 and 2 inches were examined. Within each plot, trees were grouped into diameter classes, and diameter classes containing 10 or more trees were tested for uniform diameter distribution by the Kolmogorov goodness-of-fit test (Conover 1971). The uniform distribution was selected to simplify modeling movement of trees into larger diameter classes following growth. At the 0.05 level of significance, the hypothesis of uniform diameter distribution was rejected for slightly over 4% of the 1-inch classes and nearly 36% of the 2-inch classes in the mixed conifer data set. In the ponderosa pine data set, the hypothesis of uniform distribution was rejected for nearly 6% of the 1-inch classes and over 40% of the 2-inch classes. Therefore, we selected the 1-inch diameter classes as the basic unit for the model for each species represented in a stand.

Tree measurements for each plot were summarized and averaged by 1-inch diameter classes before analy-

sis to develop model relationships. Summary statistics for major diameter class attributes (d.b.h., height, and dwarf mistletoe rating (DMR) (Hawksworth 1977)) and stand characteristics (basal area and site index) are summarized in table 1. The calibration data covered a wide range of all these variables for each major species. However, use of the model relationships in stands of low density (less than 60 square feet of basal area in mixed conifer stands and less than 30 square feet of basal area in ponderosa pine stands) or on very poor or on excellent sites (site indexes less than 50 or greater than 100 feet) would be an extrapolation beyond the range of the calibration data. Also, the average basal area levels in the data are generally higher than residual stand densities left after stands are partially cut in intensive management.

Model Relationships

We developed relationships in the GENGYM model for predicting future diameter, mortality, and seedling ingrowth for a 10-year period and height and crown length using BMDP (Dixon 1983) and SAS/STAT (SAS Institute 1988) multiple and stepwise linear and nonlinear regression and discriminant analysis routines. In addition to linear forms of independent variables, we also considered in linear regression analyses various transformations, including squares, square roots, natural logarithms, squares of natural logarithms, and their reciprocals. Transformations of the dependent variables were avoided. Generally, including two forms of an independent variable was avoided except where graphical examination showed a trend in residuals. Cross products of independent variables and their transformations were avoided because they are difficult to interpret. Sensitivity analysis and graphical inspection of residuals were used to ensure each regression relationship produced reasonable predicted values across the range of calibration data.

To simplify the discussion of model relationships, the following abbreviations for variables are used:

SI = site index (feet) for Douglas-fir in the mixed conifer type or for ponderosa pine in the ponderosa pine type at base age 100 years (Edminster et al. 1991, Minor 1964),
TBA = total stand basal area (square feet per acre) of living trees,
DBH = average d.b.h. (inches) of living trees for a species in a 1-inch-wide diameter class,
DMR = average dwarf mistletoe rating (Hawksworth 1977) of living trees for a species in a 1-inch-wide diameter class.

Prediction of Diameter in 10 Years

The major driving relationship in the GENGYM model is the prediction of average d.b.h. of a full-inch diameter class at the end of a 10-year growth projection period. We tested the performance of various dependent variables related to average class d.b.h. at the end of the projection period using data for Douglas-fir in the mixed conifer type and ponderosa pine in the ponderosa pine type. These dependent variables were average class d.b.h. and basal area at the end of the period, periodic class d.b.h. and basal area growth, and the difference between the square of d.b.h. at the end of the period and the square of d.b.h. at the beginning of the period. For both forest types, the direct prediction of average class d.b.h. at the end of the period resulted in the highest correlation to periodic diameter growth as well as ending average d.b.h. Diameter classes with average d.b.h. at the end of growth period less than average d.b.h. at the beginning of the period because of mortality were deleted from the analysis. Stepwise multiple linear regression was used to fit the following model for each species:

$$\begin{aligned} DBH10 &= d0 + d1\,DBH + d2\,DMR \\ &+ d3\,TBA + d4 \ln TBA + d5\,SI \\ &+ d6\,GBATBA + d7 (\ln DBH)^2 + d8\,DBH^2 \end{aligned} \qquad [1]$$

where

DBH10 = predicted average d.b.h. at the end of a 10-year period,
GBATBA = the ratio basal area above a subject diameter class to TBA,
ln = the natural logarithm,
d*i* = coefficients to be estimated,

and all independent variables are based on values at the beginning of the projection period.

The GBATBA term is a measure of the location of a subject diameter class in the basal area distribution. It has a value of nearly 1 for the smallest diameter class and a value of 0 for the largest diameter class. After DBH, TBA or ln TBA, and GBATBA were included in the models, crown length and crown ratio were not significant variables and were dropped from the analysis. Nonlinear transformations of initial diameter were also significant for all species but aspen and other softwoods. In the mixed conifer type, periodic d.b.h. growth was most highly correlated to a linear term of TBA. In the ponderosa pine type, periodic growth was most highly correlated to ln TBA. This result for the mixed conifer type may be the result of high variability in growth response. Future analysis of additional managed stands may demonstrate a nonlinear trend with stand density similar to the ponderosa pine type. Periodic d.b.h. growth was also most highly correlated with linear DMR. This may be the result of averaging responses of trees within a diameter class that have a range of infection levels. Development of a meaningful model for other hardwoods was not possible as no significant relationship to stand variables could be developed from the calibration data; the equation for other softwoods is also used for hardwoods other than aspen.

Results of the regressions (table 2) showed that, as expected, coefficients of determination were quite high because of the strong relationship of projected diameter to initial diameter. Standard errors of estimate were fairly large, indicating a substantial amount of unexplained

Table 1.—Summary statistics for 1-inch diameter class and stand characteristics in the calibration data sets for mixed conifer stands and ponderosa pine stands in the Southwest.

Variable	Mean	Standard deviation	Minimum	Maximum
	------------------ Mixed conifer type ------------------			
		Douglas-fir		
D.b.h. (in)	10.63	7.67	0.35	40.80
Total height (ft)	40.4	27.9	5.0	156.0
DMR	1.64	1.99	0.00	6.00
Basal area (ft^2/ac)	187.1	54.0	61.3	377.0
Site index (ft)	77.5	12.5	47.1	108.3
		Ponderosa pine		
D.b.h. (in)	10.73	7.21	0.20	35.90
Total height (ft)	47.2	27.0	5.0	128.0
DMR	1.18	1.76	0.00	6.00
Basal area (ft^2/ac)	159.0	46.8	61.3	319.8
Site index (ft)	76.7	12.2	48.1	105.6
		Aspen		
D.b.h. (in)	7.22	4.63	0.18	23.00
Total height (ft)	41.7	24.8	5.0	101.0
Basal area (ft^2/ac)	199.4	53.0	61.3	377.0
Site index (ft)	76.5	11.2	48.1	100.5
		White fir		
D.b.h. (in)	7.59	6.40	0.20	37.30
Total height (ft)	30.8	23.1	5.0	115.0
Basal area (ft^2/ac)	184.4	53.5	66.9	377.0
Site index (ft)	76.1	13.4	47.1	108.3
		Blue spruce		
D.b.h. (in)	6.63	5.28	0.16	32.30
Total height (ft)	27.7	22.1	5.0	120.0
DMR	1.40	2.00	0.00	6.00
Basal area (ft^2/ac)	178.9	45.4	66.9	308.4
Site index (ft)	79.6	10.7	47.1	100.5
		Engelmann spruce		
D.b.h. (in)	7.04	5.47	0.29	24.10
Total height (ft)	29.0	24.7	5.0	110.0
DMR	1.04	1.63	0.00	6.00
Basal area (ft^2/ac)	210.8	52.9	66.9	377.0
Site index (ft)	81.3	11.5	47.1	108.3
		Southwestern white pine		
D.b.h. (in)	6.48	5.75	0.20	32.70
Total height (ft)	30.2	21.0	5.0	122.0
Basal area (ft^2/ac)	175.8	48.8	61.3	319.8
Site index (ft)	78.6	11.1	47.1	108.3
		Corkbark/Subalpine fir		
D.b.h. (in)	6.47	5.31	0.24	27.60
Total height (ft)	31.0	25.7	5.0	121.0
Basal area (ft^2/ac)	217.8	43.7	99.3	377.0
Site index (ft)	82.2	10.6	53.4	100.5
		Other softwoods		
D.b.h. (in)	2.21	1.34	0.40	5.50
Total height (ft)	13.3	8.0	5.0	36.0
Basal area (ft^2/ac)	156.8	62.0	62.4	245.6
Site index (ft)	63.3	13.8	49.9	85.9
		Other hardwoods		
D.b.h. (in)	6.40	3.48	0.90	20.30
Total height (ft)	17.9	7.8	11.0	29.0
Basal area (ft^2/ac)	158.3	29.7	108.2	242.7
Site index (ft)	80.4	10.5	65.9	105.6
	------------------ Ponderosa pine type ------------------			
D.b.h. (in)	10.17	6.56	0.24	39.80
Total height (ft)	46.5	22.2	5.3	120.0
DMR	1.06	1.65	0.00	6.00
Basal area (ft^2/ac)	115.1	50.0	21.0	303.5
Site index (ft)	80.4	13.4	33.2	116.2

Table 2.—Coefficients, goodness-of-fit statistics, and upper limit for the prediction of class average diameter at the end of a 10-year projection period (equation [1]).

		Mixed conifer type									Ponderosa pine type
		Douglas-fir	Ponderosa pine	Aspen	White fir	Blue spruce	Engelmann spruce	White pine	Corkbark/ Subalpine fir	Other softwoods	
Variables											
Intercept	(d0)	0.58234	0.26265	0.24506	0.46172	0.50941	0.67074	0.89451	0.50283	0.25897	4.10552
DBH	(d1)	0.94542	0.94001	1.01291	1.04089	1.02697	1.03068	0.95435	0.93999	1.03129	0.88872
DMR	(d2)	−0.06679	−0.04850	—	—	−0.06944	−0.04670	—	—	—	−0.06810
TBA	(d3)	−0.00251	−0.00164	−0.00085	−0.00200	−0.00358	−0.00201	−0.00122	−0.00168	−0.00020	—
lnTBA	(d4)	—	—	—	—	—	—	—	—	—	−0.83531
SI	(d5)	0.00705	0.00601	0.00631	0.00659	0.01022	0.00633	0.00159	0.00791	0.00177	0.01378
GBATBA	(d6)	−0.14044	—	—	−0.09197	—	—	−0.20815	—	—	−0.52784
$(\ln DBH)^2$	(d7)	0.15738	0.16328	—	—	—	—	0.09987	0.16235	—	0.23834
DBH^2	(d8)	—	—	—	−0.00114	−0.00099	−0.00109	—	—	—	—
Statistics											
Coefficient of determination		0.998	0.998	0.994	0.997	0.995	0.995	0.997	0.994	0.983	0.997
Standard error of estimate		0.317	0.307	0.350	0.364	0.384	0.406	0.321	0.427	0.181	0.390
Coefficient of determination for periodic dbh growth		0.393	0.238	0.111	0.231	0.273	0.139	0.095	0.205	0.254	0.598
Number of classes		3307	763	500	1622	561	525	867	276	27	2021
Maximum diameter		42	38	26	40	40	40	36	36	20	40

variability, however. The low coefficients of determination for periodic d.b.h. growth in table 2 also demonstrate this unexplained variability. Because of the large amount of unexplained variability, the relationships in table 2 cannot be depended upon to provide reliable estimates of performance for a given d.b.h. class of a certain species in a specific stand. As might be expected, the coefficient of determination for periodic growth was the highest (0.598) for the ponderosa pine type, which had the highest proportion of managed stands. Sensitivity analysis demonstrated that for large diameter classes at high stand densities and/or on low site index lands, the predicted value of DBH10 could be less than DBH at the beginning of the period. If this happens, DBH10 is set equal to DBH in the model. Periodic growth for the other softwoods is limited to 1 inch.

Figures 1a through 1h shows how the DBH10 models perform in terms of periodic diameter growth in the mixed conifer type on site index 80 lands (the approximate average site index for calibration data for both forest types) for total stand basal areas of 50 to 300 in increments of 50 square feet per acre assuming the d.b.h. class is at the middle of the stand basal area distribution. Comparison to a similar graph for the ponderosa pine type (fig. 2) demonstrates the high sensitivity of diameter growth to stand density in the ponderosa pine type relative to the mixed conifer type. This difference in sensitivity may be an artifact of the calibration data because of the relatively high proportion of managed stands for the ponderosa pine type relative to the mixed conifer type. Also of note are the relatively high growth rates at low stand densities predicted in the ponderosa pine type compared to predicted responses in the mixed conifer type. For ponderosa pine, the difference in the models between the forest types suggests the possibility that the species may indeed perform differently depending on stand species composition. Figure 3 further demonstrates this difference in periodic diameter growth for ponderosa pine in the two forest types on site index 70 lands (near the regional average site index). Comparison of the periodic diameter growth relationship for the ponderosa pine type in figure 3 to results observed in the Taylor Woods study (Ronco et al. 1985) shows similar trends with stand density, but the model for the ponderosa pine type underestimates growth response compared to the intensively managed, homogeneous stand conditions at Taylor Woods. This comparison may cast some doubt as to whether the responses observed on the Taylor Woods plots may be possible on areas of the size of delineated stands for management purposes, or whether the result of the model predictions for intensively managed stands may be adversely influenced by range of stand structures and previous management practices represented in the calibration data. In any case, the model user should sample growth rates and use the diameter growth calibration option described in appendix 1 if observed growth rates are significantly different from model predictions.

As noted above, sensitivity analysis of the ponderosa pine DBH10 equation for the mixed conifer type showed that it considerably underestimated observed response for small diameters in stands dominated by ponderosa pine or at low stand densities when compared to results from the Taylor Woods study (Ronco et al. 1985). The

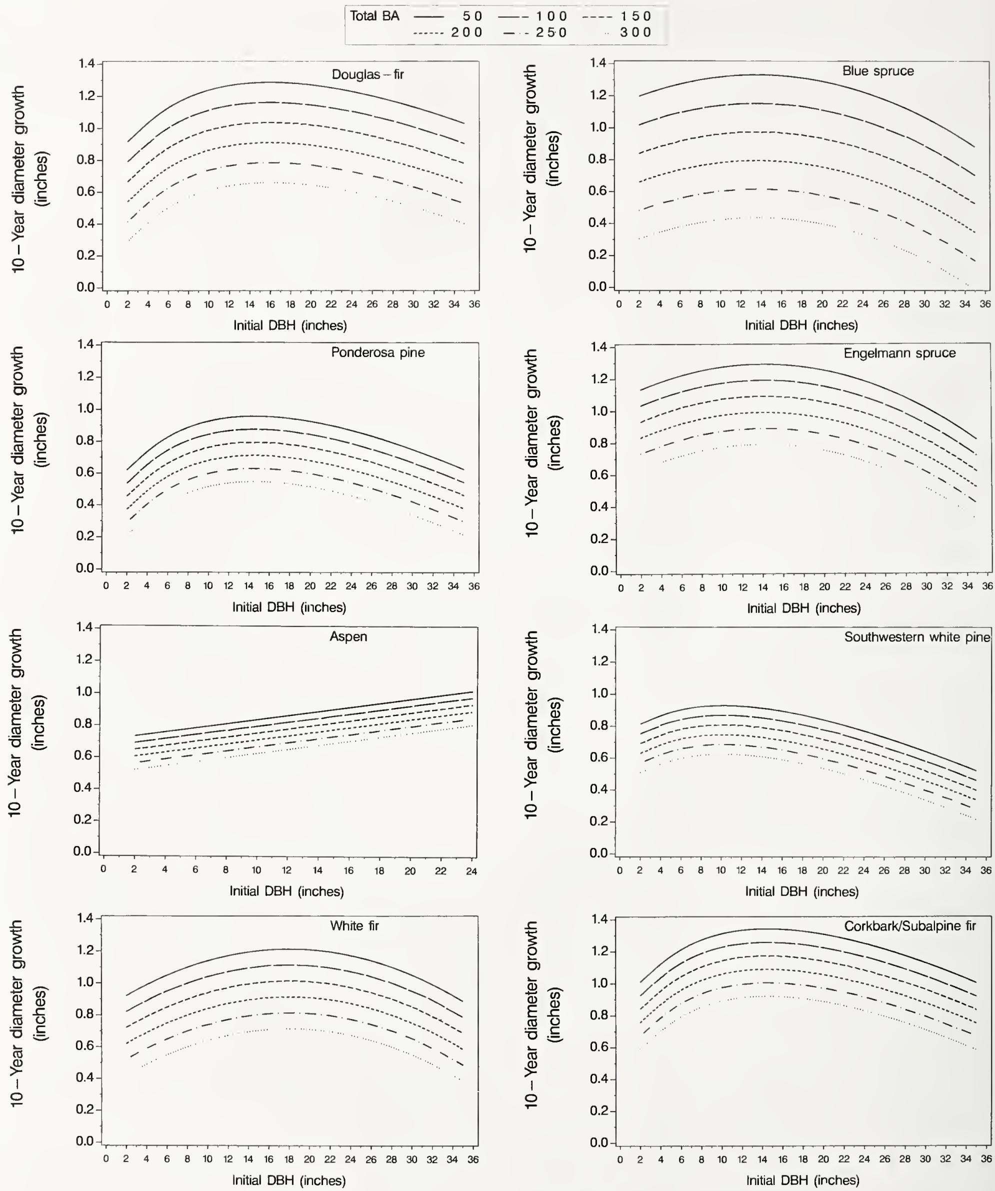

Figure 1.—Prediction of 10-year periodic d.b.h. growth for tree species in mixed conifer stands at site index 80, assuming the diameter class is at the midpoint of the basal area distribution, and total stand basal area from 50 to 300 in increments of 50 square feet per acre.

ponderosa pine type equation performed more reliably. In the model for the mixed conifer type, if TBA is less than 65 square feet per acre or the proportion of basal area in ponderosa pine is greater than 0.5, the model switches to ponderosa pine type equation. If the proportion of ponderosa pine basal area is less than 0.3 in a mixed conifer stand, the mixed conifer equation is used, and if the proportion of ponderosa pine basal area is between 0.3 and 0.5, a sliding average of the response predicted by the mixed conifer and ponderosa pine type equations is used. This switching between forest type equations produces more consistent predictions for ponderosa pine diameter response in a fairly common management scenario of favoring ponderosa pine in mixed conifer stands experiencing impacts of insects or diseases in other species.

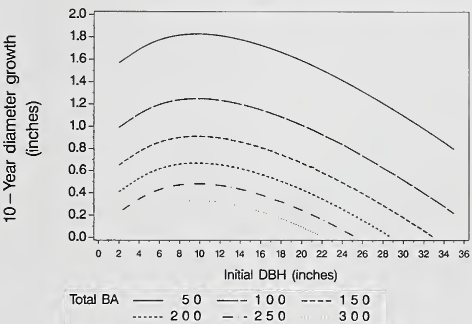

Figure 2.—Prediction of 10-year periodic d.b.h. growth for ponderosa pine in the ponderosa pine type at site index 80, assuming the diameter class is at the midpoint of the basal area distribution, and total stand basal area from 50 to 300 in increments of 50 square feet per acre.

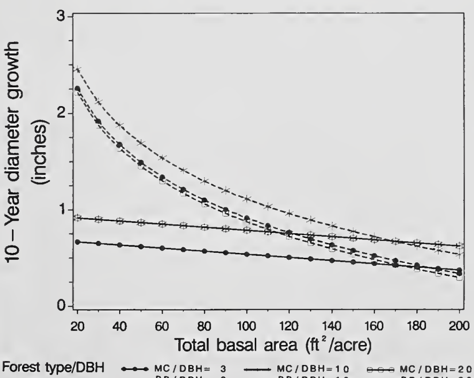

Figure 3.—Comparison of predictions of 10-year periodic d.b.h. growth for ponderosa pine in the mixed conifer (MC) and ponderosa pine (PP) types at site index 70, assuming the diameter class is at the midpoint of the basal area distribution.

Prediction of Height

A nonlinear model based on a generalization of the Richards (1959) growth curve was adopted for the prediction of average height (HT) of trees without dwarf mistletoe in a 1-inch diameter class from DBH, SI, and TBA. The Richards growth curve was selected as it is also the basis of site index curves for Douglas-fir (Edminster et al., 1991) and provides a reasonable approximation to site index curves for ponderosa pine (Minor 1964), and the curve form uses DBH as a surrogate variable for age. The height model is:

$$HT = h1\ SI^{h2}(1-\exp(h3\ DBH))^{h4\ TBA^{h5}} + 4.5 \quad [2]$$

where

hi = coefficients to be estimated,
exp = the exponential function,

and all independent variables are based on current values.

The term involving SI serves as an asymptote to the height-diameter curve. The TBA term partially determines the rate at which the curve reaches the asymptote. In higher density stands, for a given site index, it is expected that trees will have a smaller diameter but will reach the same height as in less dense stands where trees will have a larger diameter and the same height at about the same age. Coefficients and goodness-of-fit statistics for equation [2] are given in table 3. Coefficients of determination are again fairly high. However, standard errors of estimate are also fairly large, indicating unexplained variability. Height prediction in the model is bounded by the maximum height for the site index curve.

Examination of residuals from the height prediction showed the predicted height for diameter classes with DMR values greater than 0 to be greater than actual height. This increase was in addition to the effect of DMR on the prediction of d.b.h. A ratio adjustment factor (HR) was developed to account for this overestimation. The equation for the ratio adjustment took the following form:

$$HR = r0 + r1\ DMR^{0.5} + r2\ DMR^2 \quad [3]$$

where

ri = coefficients to be estimated.

This multiplicative ratio is only calculated if DMR is greater than 0. If the computed ratio is greater than 1, it is set to 1 and has no effect on height prediction. To develop the ratio model in the mixed conifer type, it was necessary to average values by DMR class. A relationship was developed for Douglas-fir and ponderosa pine (table 4), but no significant trend was found for spruce. Coefficients of determination and standard errors of estimate are based on the averaged values. A corresponding relationship previously developed for pure ponderosa pine stands (Myers et al. 1976) is used in the ponderosa pine type and is also shown in table 4. The overall contribution of these DMR impacts in predict-

Table 3.—Coefficients and goodness-of-fit statistics for the prediction of height for diameter classes without dwarf mistletoe (equation [2]).

	Mixed conifer type									Ponderosa pine type
	Douglas-fir	Ponderosa pine	Aspen	White fir	Blue spruce	Engelmann spruce	White pine	Corkbark/ Subalpine fir	Other softwoods	
Coefficients										
h1	13.09642	24.24469	14.18799	13.82209	54.18017	10.61624	18.96718	4.51429	42.26938	40.78321
h2	0.48051	0.34386	0.41652	0.46239	0.17796	0.54946	0.37979	0.75538	—	0.33261
h3	−0.07741	−0.06918	−0.12681	−0.07577	−0.08925	−0.08728	−0.07148	−0.08087	−0.16569	−0.02147
h4	1.65642	4.37952	4.05294	1.58329	1.75145	1.68717	1.83320	1.38467	1.18473	1.70985
h5	−0.06330	−0.27202	−0.24513	−0.04071	−0.02885	−0.02723	−0.09945	0.00392	—	−0.13392
Statistics										
Coefficient of determination	0.947	0.918	0.928	0.927	0.932	0.942	0.920	0.945	0.689	0.875
Standard error of estimate	6.40	7.74	6.67	6.25	5.76	5.95	5.96	6.03	4.59	8.27
Number of classes	2106	485	482	1592	387	353	836	243	23	1358

Table 4.—Coefficients and goodness-of-fit statistics for the adjustments of height to account for impacts of dwarf mistletoe (equation [3]).

		Mixed conifer type		Ponderosa pine type
		Douglas-fir	Ponderosa pine	
Variables				
Intercept	(r0)	1.09097	0.88117	0.95793
$DMR^{0.5}$	(r1)	−0.06374	0.09448	—
DMR^2	(r2)	—	−0.00631	−0.00373
Statistics for adjustment multiplier				
Coefficient of determination		0.920	0.971	
Standard error of estimate		0.010	0.007	
Statistics for final prediction of height for DMR from 0 to 6				
Coefficient of determination		0.952	0.924	0.887
Standard error of estimate		6.27	7.58	7.82

ing height is also given in table 4. While these adjustments did not result in substantial improvements over measures of goodness-of-fit for the uninfected height relationships, they did account for much of the bias observed when the uninfected relationships were applied to heavily infected diameter classes. At a class average DMR of 6, predicted height in comparison to healthy stands is 93.5% for Douglas-fir and 88.5% for ponderosa pine in the mixed conifer type, and 82.4% in the ponderosa pine type. These are relatively significant reductions and account for much of the overestimation of height when equation [2] is used in heavily infested stands.

Height growth corresponding to periodic change in d.b.h. is calculated in GENGYM by subtracting height predicted from class average d.b.h. at the beginning of the projection period from height predicted from class average d.b.h. at the end of the period. This height "growth" value is then added to class average height at the beginning of the period to compute average height at the end of the period. This approach is necessary as height growth was not directly observed on the temporary growth plots in both forest types. It has the advantage of producing estimates of periodic changes in height which are consistent with changes in diameter even if there is a substantial error in the direct prediction height from d.b.h. using equation [2] at the beginning of the period, and it does not require labor-intensive field measurements of height growth. It is, however, not possible to evaluate the height-diameter equations in terms of height growth.

Examination of the height-diameter relationship demonstrated that while it produced estimates of height development in even-aged stands consistent with two

10-year observations from Taylor Woods (Ronco et al. 1985), it generally underestimated height development in even-aged stands projected from establishment to rotation age at full stocking where stand density had a considerable effect on diameter development. To overcome this shortcoming, the model uses site index curve relationships (Edminster et al. 1991, Minor 1964) for even-aged stands to estimate periodic changes in class average height from average age rather than average d.b.h. of the class. Figure 4 presents a comparison of the predicted development of average stand height in a well-stocked plantation using the height-age relationship from site index curves and the height-diameter relationship from equation [2] on site index 70 lands in the ponderosa pine type. A multiplier based on GBATBA is used to reduce the calculated site index height for trees throughout the basal area distribution in even-aged stands. This multiplier can range from 1.0 for the largest trees to an average minimum of 0.768 observed for smaller trees in the Taylor Woods plots, and it is used for both forest types. This procedure is used for all species in even-aged stands.

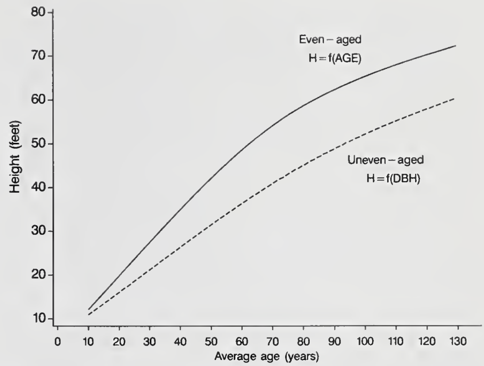

Figure 4.—Comparison of average height development projections in the ponderosa pine type using height-age relationships derived from site curves versus height-diameter relationships for a well-stocked plantation over a rotation at site index 70.

Prediction of Crown Length

While crown length was determined to be unnecessary in the prediction of future DBH, it is included in GENGYM for use in linking to other models that may require information on tree crowns. Crown length (CL) can be predicted using the following relationship:

$$CL = c0 + c1\ DBH + c2\ HT + c3\ TBA \qquad [4]$$

where

ci = coefficients to be estimated,

and all independent variables are based on current values.

Results of the regressions are given in table 5. For Engelmann spruce, corkbark fir, and other softwoods, the only significant independent variable was HT. TBA could be shown to have a significant relationship to CL for all other species, and DBH was also significant for Douglas-fir and blue spruce in the mixed conifer type and ponderosa pine in the ponderosa pine type. Coefficients of determination were relatively high. However, standard errors of estimate were about the same as for height prediction.

Prediction of Periodic Mortality

As we expected, developing meaningful relationships to predict the proportion of trees dying in a 10-year period was one of the most difficult analysis problems. For the mixed conifer type, reliable mortality relationships could not be developed directly because of variability in the diameter class data. An alternate approach of grouping observations into categories and predicting category average response was adopted to reduce variability. Categories were based on 5-inch-wide diameter

Table 5.—Coefficients and goodness-of-fit statistics for prediction of crown length (equation [4]).

		Mixed conifer type									Ponderosa pine type
		Douglas-fir	Ponderosa pine	Aspen	White fir	Blue spruce	Engelmann spruce	White pine	Corkbark/ Subalpine fir	Other softwoods	
Variables											
Intercept	(c0)	6.47479	5.63367	5.17281	6.22959	3.61635	1.05857	3.03832	0.50706	−0.59373	4.35671
DBH	(c1)	0.54482	—	—	—	0.93639	—	—	—	—	0.84714
HT	(c2)	0.50703	0.56252	0.32552	0.67587	0.61547	0.68442	0.65587	0.73070	0.67703	0.32546
TBA	(c3)	−0.03326	−0.06411	−0.01675	−0.03098	−0.02360	—	−0.01792	—	—	−0.03802
Statistics											
Coefficient of determination		0.866	0.759	0.601	0.879	0.937	0.906	0.854	0.923	0.754	0.860
Standard error of estimate		7.33	8.57	6.39	6.32	5.70	6.50	6.13	6.13	3.13	5.08
Number of classes		3316	759	540	1663	601	553	939	297	28	034

classes; basal area classes were 50 square feet per acre; and DMR classes were 0–1.5, 1.5–2.5, 2.5–3.5, 3.5–4.5, and greater than 4.5. The following model was then fit to average values for the categories for the mixed conifer type:

$$PMRT = m0 + m1\ DBH + m2 \ln DBH + m3\ DMR + m4 \ln(DMR+1) + m5 \ln TBA \qquad [5]$$

where

PMRT = the proportion of trees dying in a 10-year period,
m*i* = coefficients to be estimated,

and all independent variables are based on values at the beginning of the projection period.

Results of the regressions are shown in table 6. Even with this averaging, the relationships were fairly weak, as shown by the coefficients of determination and the large standard errors of estimate, which are based on average values for the categories. In the model if DBH is less than 1, DBH is set to 1 before PMRT is computed. These mortality relationships are also used for seedlings with DBH set to 1. If a predicted value of PMRT is less than 0 or greater than 1, PMRT is set to 0 or 1, respectively. The equation for predicting ponderosa pine mortality in mixed conifer stands was especially disappointing as the only significant independent variable was DBH, and mortality could not be shown to be related to DMR or stand density.

The availability of a large proportion of data from managed stands in the ponderosa pine type allowed us to develop an alternative model for mortality. The prediction of mortality was viewed as a two-step process. The first step was to determine if mortality was expected, and if so, then predict how much mortality would result in a given diameter class. Nearly 2,200 diameter classes with initial average d.b.h. greater than 1 inch were placed into one of two groups; those with no periodic mortality (1,787 classes) and those with some or all trees in the class dying (409 classes). Discriminant analysis was then used to develop classification functions for predicting in which group an observation belonged. An alternative method using stepwise logistic regression with equal prior probabilities and prior probabilities set to observed probabilities for each group was also attempted. Classification functions developed from discriminant analysis consistently gave the highest jackknifed estimate of correct classification for the two groups. The resulting classification functions were:

$$CFNOMT = -7.79362 - 0.05756\ DMR + 0.05970\ SUMGBA + 4.98881 \ln DBH \qquad [6a]$$

$$CFMT = -7.18284 + 0.22635\ DMR + 0.07194\ SUMGBA + 3.83471 \ln DBH \qquad [6b]$$

where

CFNOMT = the classification function for group with no mortality,
CFMT = the classification function for group with mortality,
SUMGBA = sum of basal area in classes larger than the subject class,

and all independent variables are based on values at the beginning of the projection period.

A particular diameter class is placed into one of the two groups by computing the classification function value for each group and assigning the class to whichever group has the largest classification function value. The jackknifed estimate of correct classification for the group with no mortality was 76.8%, and for the group with mortality, 73.3%. Next, we developed an equation to predict how much mortality occurred in classes with observed mortality. Number of trees dying in a class during a 10-year period, basal area dying, and the proportion of trees dying were considered as dependent variables in the analysis. Stepwise regression was used to develop prediction equations for each dependent variable. Predicting basal area dying produced the strongest relationship:

$$BADEAD = -1.12415 + 0.16371\ BA + 0.64849\ DBH + 0.08453\ DMR - 0.02966\ TBA + 0.03523\ SUMGBA - 1.71779 \ln DBH \qquad [7]$$

Table 6.—Coefficients and goodness-of-fit statistics for the prediction of 10-year periodic mortality in mixed conifer stands (equation [5]).

		Douglas-fir	Ponderosa pine	Aspen	White fir	Blue spruce	Engelmann spruce	White pine	Corkbark/Subalpine fir
Variables									
Intercept	(m0)	−0.22907	0.41255	0.02463	−0.10203	0.03300	0.09457	−0.03913	−2.41352
DBH	(m1)	—	—	—	—	—	−0.00652	—	—
ln (DBH)	(m2)	−0.09500	−0.15839	−0.18791	−0.02320	—	—	−0.01778	−0.14639
DMR	(m3)	—	—	—	—	0.01729	—	—	—
ln (DMR+1)	(m4)	0.04918	—	—	—	—	0.04275	—	—
ln (TBA)	(m5)	0.09196	—	0.09173	0.03939	—	—	0.01568	0.52624
Statistics									
Coefficient of determination		0.547	0.692	0.782	0.207	0.226	0.129	0.378	0.604
Standard error of estimate		0.072	0.070	0.047	0.037	0.055	0.074	0.013	0.127
Number of classes		86	18	12	21	21	22	12	9

where

BADEAD = basal area (square feet per acre) in the diameter class dying during a 10-year projection period,

BA = initial basal area in the diameter class,

coefficient of determination = 0.577,

standard error of estimate = 1.27 square feet per acre,

and all independent variables are based on values at the beginning of the projection period. If the estimate of BADEAD is greater than or equal to BA, all trees in the class are assumed to die. If BADEAD is negative, no mortality is assumed.

Mortality relationships for ponderosa pine in the mixed conifer type and the ponderosa pine type are compared in figure 5. The dotted line represents the mixed conifer equation, which is only related to class average d.b.h. For the ponderosa pine type, DMR for each diameter class is assumed to be 0, diameter classes up to 20 inches are assumed present in each stand, and each diameter class is assumed to contain an equal proportion of total stand basal area. The upper dark dashed and solid negative sigmoid curves in the figure are the posterior probabilities of mortality occurring derived from the classification functions (Afifi and Clark 1984) for TBA equal to 200 and 100 square feet per acre, respectively. Note that no mortality is assumed to occur when the posterior probability falls below 0.5. The lower dashed and solid curves are the percent mortality predicted to occur from equation [7] for TBA equal to 200 and 100 square feet per acre, respectively. The shape of these curves in the figure are dependent on the assumption that all classes contain equal basal area. In reality, most stands will have a higher proportion of basal area in larger diameter classes, which would cause the percent mortality curves to have a negative slope.

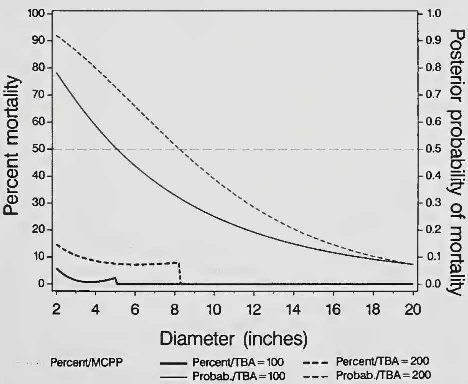

Figure 5.—Comparison of periodic mortality prediction for ponderosa pine in the mixed conifer type (MCPP) and mortality predictions based on posterior probabilities of mortality derived from classification functions and subsequent prediction diameter class basal area expected to die in the ponderosa pine type for total stand basal areas of 100 and 200 square feet per acre.

Because the ponderosa pine mortality equation for the mixed conifer type is not sensitive to stand density or structure, it overestimates mortality for small diameters in stands with a high proportion of ponderosa pine or at low stand densities. In these situations, the model switches to the mortality relationships for the ponderosa pine type in a manner similar to that described for diameter projection. Recent studies of the life expectancy of ponderosa pines with a DMR of 6, conclude that 50% of the trees will die in a 10-year period (Hawksworth and Geils 1990). If predicted mortality from the above equations is less than 50% for classes with a DMR of 6, it is set to 50% in the model.

Periodic Ingrowth of Seedlings

An estimate of the proportion of seedlings moving into measurable diameter classes in a 10-year projection period is needed if seedling height growth rates are not provided by the user as described in appendices 1 and 2. For only three species in the mixed conifer type—Douglas-fir, white fir, and southwestern white pine—was it possible to develop a very weak relationship to TBA. Mean values were used for the other species. For those species with a significant relationship to TBA, the model was:

$$PIN = s0 + s1\ TBA \qquad [8]$$

where

PIN = the proportion of seedlings growing over b.h. in a 10-year period,

si = coefficients to be estimated,

and TBA is based on the beginning of the projection period.

Results of the regression analysis are given in table 7. Because of the poor relationship to stand characteristics, the user is strongly encouraged to provide stand specific height growth estimates for seedlings rather than rely on the default relationships presented in table 7. Data to develop similar relationships for the ponderosa pine type were not available, and the user must input height growth estimates for the type as described in appendices 1 and 2.

Computation of Volume

Volumes are computed from average diameter and height within a diameter class using tree volume equations developed by Hann and Bare (1978). Only equations for gross volumes inside bark for unforked trees are included. Volume equations compute total cubic feet including the stump and top, merchantable cubic feet excluding the stump and top, and board feet Scribner rule of the merchantable stem excluding the stump and top. In the current version of GENGYM, no volumes are computed for other softwoods or other hardwoods.

Periodic Intensification of Dwarf Mistletoe

Intensification of dwarf mistletoe in Douglas-fir is based on individual tree relationships developed by

Table 7.—Coefficients and goodness-of-fit statistics for the prediction of the proportion of seedlings moving above b.h. in a 10-year period in mixed conifer stands (equation [8]).

	Douglas-fir	Ponderosa pine	Aspen	White fir	Blue spruce	Engelmann spruce	White pine	Corkbark/ Subalpine fir	Other softwoods
Variables									
Intercept (s0)	0.30817	0.09751	0.07474	0.35520	0.13451	0.11624	0.22407	0.06050	0.0752
TBA (s1)	−0.00078	—	—	−0.00109	—	—	−0.00077	—	—
Statistics									
Coefficient of determination	0.061	—	—	0.158	—	—	0.114	—	—
Standard error of estimate	0.154	0.128	0.114	0.141	0.145	0.138	0.106	0.067	0.0753
Number of plots	203	47	110	180	77	58	127	40	16

Geils and Mathiasen (1990). The probabilities associated with an individual tree increasing 0, 1, 2 or more classes are used to compute an expected increase for trees within a diameter class with a given initial average DMR. Intensification for ponderosa pine is based on the whole stand relationships used by Myers et al. (1976). While these intensification relationships are strictly applicable to pure ponderosa pine stands, they are the best available information for use in mixed conifer stands as well. No intensification relationships are available for blue spruce or Engelmann spruce. The Douglas-fir relationship is used in GENGYM for both spruces.

Dwarf mistletoe affects diameter projection, height prediction, and mortality relationships in GENGYM. To demonstrate the cumulative effects on stand level projections of the intensification and impacts relationships for dwarf mistletoe, a hypothetical stand was created by splitting off the Douglas-fir component of the stand used in the appendices. This pure Douglas-fir stand represents a well-stocked stand with irregular stand structure growing on site index 80 land. Two runs of the model for a time period of 100 years each were made with no intermediate treatments. The first run assumed no infestation by dwarf mistletoe, and the second run assumed all diameter classes had a DMR of 1 at the initial age. Results of the simulations are shown in figure 6, which compares merchantable cubic volume production for the two scenarios. At the end of 100-year simulation, the uninfested stand is projected to contain about 9,500 merchantable cubic feet per acre. Volume production in the infested stand is projected to reach a maximum of about 6,300 merchantable cubic feet per acre in 50 years and then decline to near the initial volume. Increased mortality in the heavily infested smaller diameter classes is the primary cause for this volume decline.

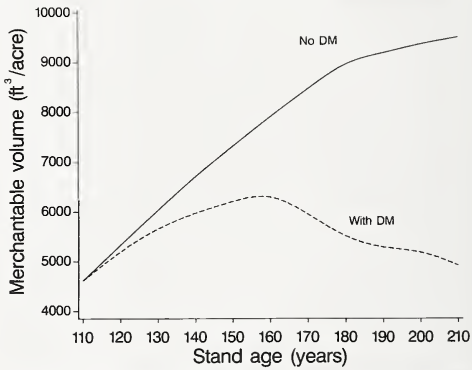

Figure 6.—Comparison of projections of merchantable volume production in a well-stocked pure Douglas-fir stand with irregular structure at site index 80, without infection by dwarf mistletoe (NO DM), and the same stand lightly infested with dwarf mistletoe at the initial age (WITH DM).

Verification of Model Relationships

The 20 plots deleted from the calibration data for the mixed conifer type were used in an independent examination of the principal relationships in the GENGYM model. Tree measurements from the plots were summarized by 1-inch diameter class in the same manner as tree measurements from the calibration data. The verification data included all the major species. Adequate data were not available for other softwoods or hardwoods. Total stand basal area ranged from 93 to 250 square feet per acre, with a mean of 168. The site index range was 56 to 102 feet, with a mean of 78. The data available from the verification data allowed for examination of the future diameter, height, crown length, and proportion of mortality relationships. Application of the prediction equations presented earlier to observations in the verification data resulted in the residuals summarized in table 8. The residuals were also graphed against the independent variables in each relationship. Other than a bias in prediction for some relationships, no other consistent trends in the residuals were evident in the graphs.

The relationships for the prediction of diameter at the end of a 10-year growth period were supported by the verification data for Douglas-fir, ponderosa pine, aspen, white fir, and blue spruce in the mixed conifer type. Relationships for Engelmann spruce, southwestern white pine, and corkbark/subalpine fir resulted in significant underestimation of diameter at the end of a 10-year period. Examination of the observations in the

Table 8.—Summary statistics for residuals from verification of major model relationships.

Variable		Mean	Standard error	Minimum	Maximum	Number of classes
			Mixed conifer type			
			Douglas-fir (20 plots)			
DBH10		0.034	0.020	−0.82	1.56	293
HT		−0.34	0.37	−25.2	23.3	293
CL		−0.17	0.38	−16.2	19.8	287
PMRT		0.001	0.011	−0.32	0.91	299
			Ponderosa pine (13 plots)			
DBH10		0.053	0.050	−0.59	1.49	69
HT		−0.30	0.78	−16.8	15.3	69
CL		−1.52	1.00	−25.8	21.0	66
PMRT		−0.022	0.018	−0.46	0.41	69
			Aspen (13 plots)			
DBH10		−0.026	0.038	−0.56	1.14	67
HT	(S)	−3.06	0.81	−20.8	11.2	67
CL		0.41	0.71	−10.6	17.7	65
PMRT	(S)	−0.097	0.035	−0.53	0.95	71
			White fir (20 plots)			
DBH10		0.080	0.041	−0.67	1.98	141
HT	(S)	−1.09	0.43	−13.6	11.5	141
CL		0.80	0.48	−21.8	18.8	137
PMRT	(S)	−0.032	0.008	−0.13	0.46	141
			Blue spruce (7 plots)			
DBH10		0.126	0.085	−0.69	1.79	35
HT		0.41	1.27	−15.8	20.5	35
CL	(S)	1.74	0.85	−8.1	12.5	34
PMRT		−0.003	0.025	−0.10	0.47	35
			Engelmann spruce (8 plots)			
DBH10	(S)	0.148	0.062	−0.73	1.40	48
HT	(S)	−2.30	0.81	−13.4	14.6	48
CL	(S)	3.85	1.00	−16.1	18.8	46
PMRT		−0.042	0.022	−0.14	0.99	49
			Southwestern white pine (15 plots)			
DBH10	(S)	0.137	0.048	−0.45	1.20	86
HT		−0.83	0.71	−25.2	21.9	86
CL		−0.09	0.65	−11.3	18.8	86
PMRT		−0.002	0.006	−0.07	0.31	86
			Corkbark/Subalpine fir (6 plots)			
DBH10	(S)	0.488	0.089	−0.45	1.88	37
HT		−0.69	0.97	−16.7	14.3	37
CL	(S)	2.52	0.88	−10.2	13.8	36
PMRT		−0.045	0.034	−0.52	0.50	37
			Ponderosa pine type			
			Ponderosa pine (26 plots)			
DBH10		0.038	0.027	−1.04	1.47	303
HT	(S)	1.06	0.41	−15.74	26.47	294
CL		−0.57	0.30	−21.07	16.94	294
BADEAD		−0.039	0.052	−4.18	8.53	308
			Douglas-fir (23 plots)			
DBH10	(S)	0.177	0.061	−0.71	1.84	87
HT	(S)	−2.54	0.63	−19.95	11.48	87
CL	(S)	4.52	0.69	−8.01	16.00	59
PMRT	(S)	−0.073	0.015	−0.26	1.00	88
			White fir (16 plots)			
DBH10	(S)	0.197	0.084	−0.96	1.63	60
HT		−0.89	0.65	−24.92	11.61	60
CL		2.00	1.05	−3.38	14.61	16
PMRT		−0.006	0.020	−0.09	1.00	60

(S) indicates a significant difference from 0 at the 0.05 significance level.

verification data showed that for each species, tree age was considerably younger than the average ages in the calibration data. Although age was not significantly related to diameter growth after diameter was included in model relationships from the calibration data, this result supports closer examination of diameter development as related to tree age in future modeling. The results for Engelmann spruce and corkbark/subalpine fir may also suggest that relationships developed from the mixed conifer type may underestimate performance of these species, which are usually associated with the higher elevation spruce-fir type. While the differences for Engelmann spruce and white pine were not too much greater than normal measurement error, the mean residual for corkbark fir was substantially larger. The amount of variability for all species can be seen by examining the maximum and minimum values for the residuals. The user of the model is strongly encouraged to sample growth responses and use the diameter growth calibration available, if observed growth rates are substantially different from model predictions.

Model relationships for the direct prediction of height were supported by the verification data for Douglas-fir, ponderosa pine, blue spruce, southwestern white pine, and corkbark/subalpine fir. The relationships for aspen, white fir, and Engelmann spruce resulted in significant overestimation. Again observations for these species were from trees with younger average age than the calibration data. The method used in the model of indirectly deriving change in height based on change in diameter over a 10-year period results in actual height predictions consistent with height growth trends from whole-stand models for Engelmann spruce and aspen, however (Edminster 1978).

Relationships for the direct prediction of crown length underestimated observed values for blue spruce, Engelmann spruce, and corkbark fir. These results further supported not using crown length as an independent variable in diameter prediction function.

Relationships for the prediction of proportion of mortality were supported by the verification data for Douglas-fir, ponderosa pine, blue spruce, Engelmann spruce, southwestern white pine, and corkbark/subalpine fir. Mortality was significantly overestimated for aspen and white fir. As noted earlier, average age for both species in the verification data was younger than in the calibration data. Results for these species may just be due to variability in the samples, or they may be indicative of increased incidence of disease impacts in older trees in the calibration data. While the mortality relationships in GENGYM seem to produce reasonable results on an average regional basis, they may not produce reliable results when applied to a specific set of stand conditions. Because of the highly variable nature of mortality both in time and location, the user is again encouraged to employ mortality adjustments available in GENGYM if observed and predicted mortality are substantially different.

Based on this limited examination of the performance of the mixed conifer relationships, it seems that species also associated with the higher elevation spruce-fir type (Engelmann spruce, corkbark/subalpine fir, and aspen), as well as shade-tolerant white fir, are most likely to exhibit growth and mortality responses different from model relationships. The mixed conifer data best represent stands dominated by Douglas-fir. Model relationships may not perform reliably in stands where other species comprise the dominant component.

For the ponderosa pine type, the 26 plots deleted from the calibration data were available for an independent examination of model relationships. Average total stand basal area in the verification data was 113 square feet per acre, with a range of 19 to 226. The site index range was 60 to 104 feet, with a mean of 80. For species other than ponderosa pine, relationships from the mixed conifer type were used because of inadequate calibration data. Limited observations for Douglas-fir and white fir in the plots selected for model calibration were included in the verification data. Use of the mixed conifer type relationships for species other than ponderosa pine assumes that relative site quality is similar for both forest types. The user is cautioned that adequate data are not available to support this assumption. In addition, the use of the mixed conifer type relationships assumes similar species responses regardless of the dominant species in the stand. As shown earlier, this apparently does not hold for ponderosa pine when relationships for the two types are compared.

For ponderosa pine, all major model relationships were supported except the direct prediction of height from diameter. Examination of the residual plots for estimated periodic diameter growth showed a general underestimation of response at low stand densities, however, indicating the user should use the diameter growth calibration feature in the model for stands that are to be managed at low densities. Examination of the verification data showed a higher proportion of even-aged plots than in the calibration data. Use of height-age relationships based on site index in the even-aged plots of the verification data resulted in a nonsignificant mean residual, supporting the use of these relationships in the model as described earlier. The examination of mortality for ponderosa pine included applying the classification functions to determine if mortality was expected and the BADEAD relationship to predict the amount.

Data for Douglas-fir in the ponderosa pine type did not support the use of the mixed conifer relationships. The Douglas-fir data represented very young trees compared to the calibration data for the mixed conifer type. Average age of the Douglas-firs in the ponderosa pine type was 42 years, with a maximum of 80 years. The performance of relatively young trees may be the reason for the underestimation of diameter growth response compared to the mixed conifer type data, which included older trees and more diverse stand structures. Or the result may suggest that the response of Douglas-fir is different in stands dominated by ponderosa pine compared to stands where it is the dominant species. In addition, only negligible mortality was observed for Douglas-fir. Unfortunately, the limited data available for Douglas-fir in the ponderosa pine type do not allow sup-

portable conclusions. Regardless of the reasons for the poor performance of the mixed conifer type equations for Douglas-fir in the ponderosa pine type, the user is encouraged to sample Douglas-fir response before accepting model relationships without calibration.

Data for white fir in the ponderosa pine type supported the use of mixed conifer type relationships except for the prediction of diameter. Again this may be the result of simpler stand structures in the ponderosa pine type, or may indicate a difference in response of white fir depending on the dominant overstory species.

Model verification demonstrated that the response of the dominant species in each forest type in the Southwest appears to be well described by the model. This limited examination of the reliability of the prediction functions in GENGYM is not intended to replace an independent validation using plot data from a designed study. The purpose was to assess in an informal manner the reliability of the equations when applied to specific stands. While the calibration functions in GENGYM seem to produce reasonable results, the above verification points to the variability in actual outcomes that may result when the relationships are applied to a single plot or stand of interest. The model allows the user to calibrate the diameter and mortality prediction functions to current observed levels if this is needed to produce reliable results. Variability in stand response was large in the data set used for calibration. Some of this variability undoubtedly results from the complex stand structures and species compositions encountered. As more stands are brought into managed conditions, some of the variability in response should be reduced. There continues to be a need to establish designed permanent plots to further investigate and calibrate the relationships presented above over long periods of time.

A final caution to the user of GENGYM is that model performance has not been adequately tested in stands managed by use of group selection cutting methods. The model uses total stand basal area as the measure of stand density. Within individual groups, density effects will probably be considerably different from that represented by average density for the stand. Calibration features for diameter growth and mortality in the model may not be adequate to account for the response of trees in the groups or on the edge of groups. It may be necessary to model group conditions separately and integrate group responses to project stand response.

Model Structure and Operation

Program GENGYM for IBM PC's[3] and compatibles, as calibrated for the mixed conifer and ponderosa pine forest types in the Southwest, consists of a main program and 25 subroutines. The program is written in a modular form designed for expansion to other forest types. The program has been developed using the Microsoft[3] FORTRAN version 5.0 compiler running under Microsoft DOS version 4.01 operating system. The object code has been linked to the emulator mathematics package to allow use of the executable file on PC's with or without a mathematics coprocessor. The executable file is less than 177 kilobytes in size. The only nonstandard code is a call in subroutine TABLE to date and time subroutines available in Microsoft FORTRAN to label the output tables for future reference. The program is executed by entering GENGYM at the DOS prompt.

A flow diagram (fig. 7) shows the order of program execution and subroutine calls. The main program begins processing by opening required input files (GENINP.CTL and GENINP.DAT) and output files (GENOUT.DBH. GENOUT.SPP, GENOUT.STD, GENOUT.NET, GENOUT.DAT). The input files must exist in the subdirectory from which GENGYM is executed or an error will result that terminates processing. To avoid possible partial overwriting, the output files must not exist in the subdirectory from which GENGYM is executed as they are created by GENGYM. The main program then reads controls from the first three records in file GENINP.CTL. (See appendix 1 for record contents and formats for file GENINP.CTL.) Subroutine DATIN initializes storage variables and arrays and reads in stand inventory data in diameter class format from file GENINP.DAT. (See appendix

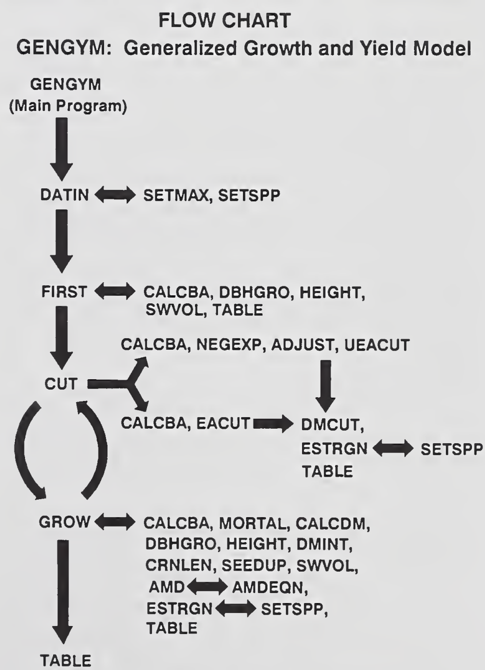

Figure 7.—Flow diagram of GENGYM execution.

[3]*The use of trade and company names is for the benefit of the reader; such use does not constitute an official endorsement or approval of any service or product by the U.S. Department of Agriculture to the exclusion of others that may be suitable.*

2 for record contents and formats for file GENINP.DAT.) Subroutine SETMAX sets upper limits on diameters for all species represented in the model. Subroutine SETSPP then assigns the proper species array value based on forest type and standard inventory code.

The main program then calls subroutine FIRST to compute initial values of stand characteristics from the values of variables in file GENINP.DAT. Subroutine CALCBA computes the basal area distribution, and subroutine DBHGRO is called if diameter growth calibration to inventory growth rates is requested by the user on record 3 of file GENINP.CTL. Subroutine HEIGHT computes missing heights. Subroutine SWVOL computes initial volumes. The last operation in subroutine FIRST calls the output subroutine, TABLE, to write initial stand characteristics to the output files.

The main program then begins a series of sequential calls to subroutines CUT and GROW to execute scheduled cutting operations and periodic growth projections, respectively, for as many cuts and projection periods as specified in record 1 of file GENINP.CTL. Subroutine TABLE is also called by subroutines CUT and GROW to write removals and residual stand characteristics from each cutting operation and stand conditions at the end of each projection period into the output files. The output files GENOUT.DBH, GENOUT.SPP, and GENOUT.STD contain stand conditions at the diameter class level, summarized by species and whole stand, respectively. Volumes in these three output files are based on gross volume equations (Hann and Bare 1978). File GENOUT.DBH contains stand table information for each species present in the stand. File GENOUT.STD resembles a whole stand yield table produced by program RMYLD (Edminster 1978). File GENOUT.NET is also a whole stand summary file except that volumes are based on adjustments from gross to net and stockable area contained on record 3 in file GENINP.CTL. An additional file, GENOUT.DAT, is provided that contains diameter class values at each period in input file format. This file may be useful to users wishing to simulate cutting operations not currently available in the model. The user can edit the GENOUT.DAT file to reflect the desired treatment, rename the file to GENINP.DAT, and resume running the model.

Subroutine CUT is called by the main program to execute intermediate partial cuts, regeneration cuts, and final removals. Subroutine CALCBA first determines stand density and basal area distribution before the cut is attempted. If stand density does not exceed residual density goals, then the routine skips over cutting operations. Even-aged and uneven-aged cutting options are available. Cutting options are controlled by values of variables contained in record 4 of file GENINP.CTL.

Subroutine CUT calls the cutting routine EACUT to perform all even-aged cutting from above or below. EACUT performs removals in a mechanistic manner from above or below according to species priority set on record 2 of input file GENINP.CTL until desired residual stand density, expressed as trees per aces, basal area per acre, or percent of current basal area is attained.

In addition to even-aged cutting, an uneven-aged cutting option is available in subroutine CUT. Subroutines NEGEXP, ADJUST and UEACUT are called in succession to perform uneven-aged cutting. First, subroutine NEGEXP computes the desired residual diameter distribution using methods presented by Alexander and Edminster (1977). The q-ratio used in GENGYM is for 1-inch diameter classes, which is the square root of the Q-ratio for 2-inch diameter classes. Subroutine ADJUST then balances surpluses and deficits between the actual stocking curve and desired residual curve computed by subroutine NEGEXP. If a deficit exists between the actual stocking curve and the desired residual curve for a particular diameter class, successive adjacent diameter classes are examined to make up the deficit stocking. Using these stocking adjustments, subroutine UEACUT then actually performs the cutting. The results of uneven-aged cutting in a stand of irregular structure are shown in figures 8a (trees per acre) and 8b (basal area).

If a cut that includes provision for controlling dwarf mistletoe is being simulated, subroutine CUT calls subroutine DMCUT to estimate residual DMR levels us-

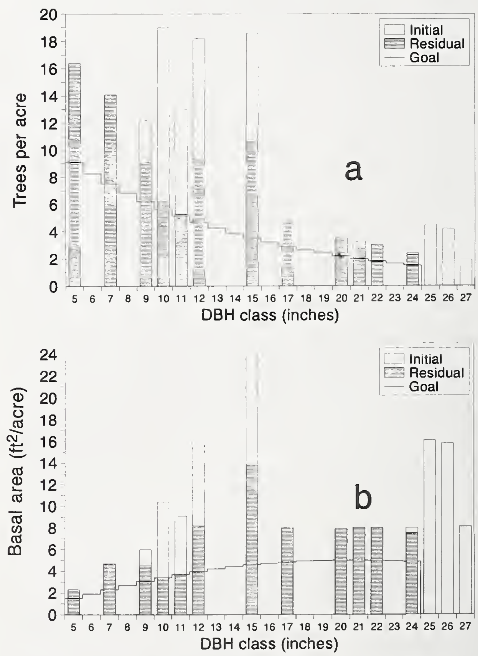

Figure 8.—Example of uneven-aged cutting in an irregular stand to a residual basal area of 80 square feet per acre, a q-ratio of 1.1, and a regulated diameter range of 5 to 24 inches, demonstrating how subroutines UEACUT, NEGEXP, and ADJUST balance deficits in stocking below the goal line by retaining surplus trees in adjacent diameter classes: a, in terms of trees per acre; b, in terms of basal area per acre.

ing relationships of proportion of trees infected to DMR (Myers et al. 1976). If dwarf mistletoe is present in Douglas-fir, ponderosa pine, Engelmann spruce, or blue spruce, subroutine DMCUT assumes that cutting will remove infested trees first in computing a new proportion of residual trees infested to compute residual DMR.

Subroutine CUT then checks to see if regeneration establishment is scheduled to occur (record 5 of file GENINP.CTL). If regeneration establishment is scheduled, subroutine ESTRGN adds new seedlings to the stand table.

Subroutine TABLE is then called to write removal and residual stand characteristics to the output files. After a call to subroutine CUT, the main program attempts to read another set of cut controls from file GENINP.CTL. If another cut is scheduled for the current time period, the main program calls subroutine CUT again. This provision allows for multiple cuts to occur at a single time period. If a cut is scheduled for a later time period, this information is stored and accessed after the required number of growth projections has been made.

Subroutine GROW is called by the main program to perform all operations associated with periodic mortality and growth projections. For species other than ponderosa pine in the ponderosa pine forest type, mixed conifer relationships are used because of a lack of adequate calibration data for other species in the ponderosa pine type. If the specified projection period is less than 10 years (record 1 of file GENINP.CTL), the mortality, future diameter, and dwarf mistletoe intensification computations are adjusted for a proportion of a 10-year period. The subroutine first calls subroutine CALCBA to establish a basal area distribution and total stand density at the beginning of the projection period. Next subroutine MORTAL reduces seedling and tree density to account for periodic mortality. Subroutine CALCDM then computes the DMR distribution by species and diameter class at the beginning of the projection period. Starting with the largest diameter class and working down to the smallest diameter class, successive calls are made to subroutine DBHGRO, which contains the future diameter regression equations. If the projected diameter exceeds maximum values set in subroutine SETMAX, the projected diameter is set to the maximum value. For each diameter class of each species, a future diameter is calculated and, based on this new diameter value, trees are moved into new 1-inch classes.

The process of moving trees after a new diameter is projected is best demonstrated with an example (fig. 9). Suppose the initial average d.b.h. for a class is 8.5 inches, and after a call to DBHGRO, the average d.b.h. at the end of the projection period is estimated to be 9.2 inches. A temporary 1-inch-wide class value is constructed around 9.2 inches. This temporary class extends from 8.7 to 9.7 inches (9.2 ± 0.5). The break between the usual full-inch classes occurs at 9 inches (the largest integer less than 9.7). The next computation involves determining the proportion and average diameter of trees that remain below and move above the full-inch class break of 9 inches. When the simplifying assumptions of the uniform distribution is used, the proportion of trees

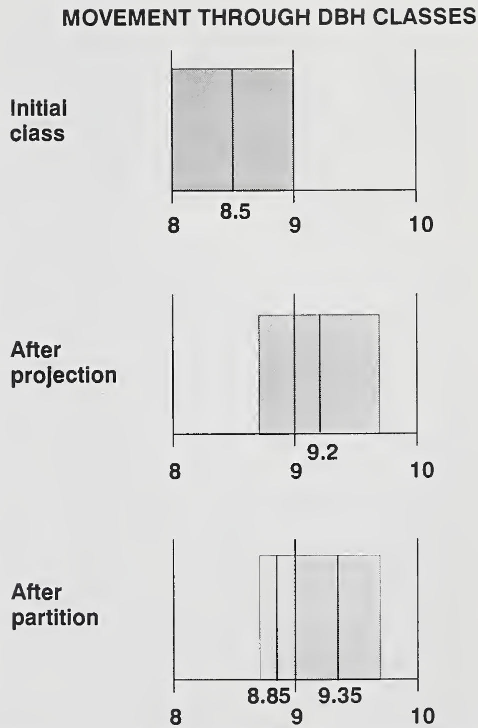

Figure 9.—Diagram of movement of a diameter class after growth projection and subsequent partitioning into two classes at the diameter class break in subroutine GROW.

below 9 inches is 0.3 (9 – 8.7), and the proportion above 9 inches is 0.7 (9.7 - 9). The average diameter below the break is 8.85 inches (the average of 8.7 and 9), and the average diameter above the break is 9.35 inches (the average of 9 and 9.7). These proportions of trees and new average diameters are then used to split the former temporary diameter class centered at 9.2 inches into full-inch classes for 8-inch and 9-inch trees. The values for the 8-inch class will be averaged with trees moving into the class from below, if any, and the values for trees that moved into the 9-inch class will be averaged with trees that remained in that class, if any.

Subroutine GROW then calls subroutine HEIGHT to estimate an average total height corresponding to the initial average d.b.h. and the d.b.h. at the end of the projection period (8.5 and 9.2 inches, respectively, in the example above). The difference between these estimated heights is then added to the actual initial average height to arrive at the expected height at the end of the projection period. A ratio of change in height to change in d.b.h. for the projection period is computed and used to compute the average height of trees above and below

the full-inch class diameter break. Average age is incremented by adding the length of the projection period.

Subroutine CRNLEN then computes a new crown length corresponding to the average d.b.h. and height values above and below the diameter break. If the estimated crown length from CRNLEN is greater than the initial crown length, the change in crown length is limited by the computed change in average height. If the estimated crown is less than the initial crown length, the amount of decrease is bounded by 1.5 times the change in average height.

Subroutine DMINT then estimates the intensification of dwarf mistletoe if present in Douglas-fir, ponderosa pine, Engelmann spruce, or blue spruce. Using the proportion of trees, number of trees surviving, and new average characteristics computed above and below the diameter break, DMINT computes the values for the current full-inch classes by weighting by the numbers of trees moving into new classes and those remaining in former classes. Subroutine VOLUME then computes gross volumes using these new average values for each full-inch diameter class. The process is continued through the smallest diameter class for each species. Subroutine SEEDUP projects height growth of seedlings or proportion of seedlings moving above breast height into the 0-inch class. Subroutines CRNLEN and VOLUME then compute crown lengths and volumes of trees that have moved above 4.5 feet tall. Subroutine GROW then calls subroutine AMD to make any needed adjustments in stand density if the average maximum density value (Edminster et al., in press) computed by subroutine AMDEQN has been exceeded. Subroutine AMD removes a proportion of the trees in each diameter class equal to the proportion of stand density that exceeds the average maximum value and adjusts remaining volumes. If regeneration establishment is scheduled, subroutine ESTRGN is called to establish seedlings specified on record 5 in input file GENINP.CTL. Subroutine CALCBA then computes a final basal area distribution after the growth projection, and subroutine TABLE writes this to the output files.

The main program then checks to see if a cutting operation is scheduled, and if so, calls subroutine CUT. Otherwise, another call is made to subroutine GROW. This pattern continues until the final growth projection period specified (record 1 of file GENINP.CTL) is reached and the simulation run is terminated. The output files may then be examined with a text editor or printed. The output file containing net volumes (GENOUT.NET) will be empty unless net volume adjustments are specified in record 3 of file GENINP.CTL. Samples of the output files are included in appendix 3.

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Appendix 1

Format for Control Input File to GENGYM (GENINP.CTL)

VARIABLE	COLUMNS	FORMAT	DESCRIPTION
RECORD 1 – stand identification and controls			
IDREG	1–2	I2	2-digit Region code (02 or 03)
IDFOR	3–4	I2	2-digit Forest code
IDDIS	5–6	I2	2-digit District code
IDTYPE	7–10	I4	Forest type code 1 – Southwestern mixed conifer 2 – Southwestern ponderosa pine
SITE	11–15	F5.0	Site index
ISPPSI	16–20	I5	Site index species (standard 3-digit code)
NGPERS	21–25	I5	Number of growth periods
PER(1)	26–30	F5.0	Length of first growth period, 1 to 10 years. If left blank, default is 10.
PER(2)	31–35	F5.0	Length of second growth period, 1 to 10 years. If left blank, default is the length of the first period.
PER(3)	36–40	F5.0	Length of third and successive growth periods. If left blank, default is the length of the second period.
IDSTND	41–80	A40	40-character stand description
RECORD 2 – merchantable volumes and species retention priorities			
DCMIN	1–5	F5.1	Minimum d.b.h. for calculation of merchantable cubic foot volume. If left blank, default value is 5.0 inches.
DTOPC	6–10	F5.1	Minimum top d.i.b. for calculation of merchantable cubic foot volume. If left blank, default value is 4.0 inches.
DBMIN	11–15	F5.1	Minimum d.b.h. for calculation of board foot volume. If left blank, default value is 9.0 inches.
DTOPB	16–20	F5.1	Minimum top d.i.b. for calculation of board foot volume. If left blank, default value is 6.0 inches.

The following 10 variables set the species retention priorities for cutting. See the order of species and default values for each forest type given below. The lower the number, the higher the retention priority. That is, a value of 1 indicates the species will be cut only after all other species in a diameter class have been cut. Each species or species group must be given a unique value. Legal values are 1 to 10. All 10 fields must contain a value, even if a specific forest type uses less than 10 species.

ISPRI(1)	21–22	I2
ISPRI(2)	23–24	I2
ISPRI(3)	25–26	I2
ISPRI(4)	27–28	I2
ISPRI(5)	29–30	I2
ISPRI(6)	31–32	I2
ISPRI(7)	33–34	I2
ISPRI(8)	35–36	I2
ISPRI(9)	37–38	I2
ISPRI(10)	39–40	I2

DEFAULT VALUES FOR SPECIES RETENTION PRIORITIES BY FOREST TYPE

Species abbreviations:

DF	Douglas-fir
PP	Ponderosa pine
WF	White fir
BS	Blue spruce
ES	Engelmann spruce
P	Pinyon
J	Juniper spp.
SWWP	Southwestern white pine
C/SF	Corkbark / Subalpine fir
OS	Other softwoods
A	Aspen
OH	Other hardwoods

1. Southwestern Mixed Conifer Type

DF	1
PP	2
A	3
WF	4
BS	5
ES	6
SWWP	7
C/SF	8
OS	9
OH	10

2. Southwestern Ponderosa Pine Type

PP	1
DF	2
A	3
SWWP	4
WF	5
BS	6
OH	7
OS	8
P	9
J	10

ITIM	41–45	I5	Year of the inventory data in file GENINP.DAT. If left blank, default value is 0.
LCLASS	46–50	I5	Width of diameter classes in output file GENOUT.DBH. Legal values are 1, 2, and 4. If left blank, default value is 1.

RECORD 3 – calibration controls

PCTAMD	1–5	F5.0	Percent of the Average Maximum Density (AMD) curve to which the stand will be allowed to grow. Legal values are 1% to 150%. If left blank, default is 100%.
ICALV	6–10	I5	Flag to specify if a stand level yield table will be printed with adjustments of gross merchantable volumes to net. Value of 0 specifies do not print the table. Value of 1 specifies print the net volume table. If left blank, default is 0. If value is 0, leave PCNET and PBNET blank.
PCNET	11–15	F5.0	Percent by which gross merchantable cubic foot volume will be multiplied to calculate net cubic volume. If left blank, default is 100%. A value of 80 means that net cubic volume will be computed as 80% of gross cubic volume.
PBNET	16–20	F5.0	Percent by which gross board foot volume will be multiplied to calculate net board foot volume. If left blank, default is 100%.
ICALG	21–25	I5	Flag to specify if diameter growth functions should be calibrated to observed growth rates. Value of 0 specifies no calibration. Value of 1 specifies to calibrate by computing a percentage difference across d.b.h. classes and applying that difference on a stand basis. If value is 0, leave CALGYR and IATNG blank.
CALGYR	26–30	F5.0	Number of years over which the diameter growth calibration should occur. Legal values are 1 to the length of the simulation.
IATNG	31–35	I5	Flag to specify if the diameter growth calibration should remain a constant percentage difference from model functions (value of 0) or should linearly attenuate to the model functions (value of 1) over the time period CALGYR years. If left blank, default is 0.
ICALM	36–40	I5	Flag to specify if mortality functions should be adjusted. Value of 0 specifies do not adjust. Value of 1 specifies to adjust the mortality functions. If left blank, default is 0. If value is 0, leave PSAPM, PPOLM, and PSAWM blank.
PSAPM	41–45	F5.0	Percent to adjust mortality for trees in the 0.1- to 4.9-inch d.b.h. range. This mortality percent will be added to the mortality percent for numbers of trees estimated by the model functions. If left blank, default is 0. Legal values are –100 to 100. If after adjustment the percent mortality is negative, a default value of 0 will be used. In other words, a negative percent mortality will not "create" trees. This also applies to PPOLM and PSAWM.
PPOLM	46–50	F5.0	Percent to adjust mortality for trees in the 5.0- to 8.9-inch d.b.h. range.
PSAWM	51–55	F5.0	Percent to adjust mortality for trees 9.0 inches d.b.h. and larger.
PSTOCK	56–60	F5.0	Percent of stand area that is stockable. Legal values are 1% to 100%. If left blank, the default value is 100. Adjustments for stockable area are included in the GENOUT.NET output file.

As many pairs of cut control and regeneration records may be included as necessary. Multiple cuts may be specified for at any given period by including more than one Record 4 with the same value for NCPER. If no cuts are desired, do not include any Records 4 and 5. If a cut is expected to result in regeneration, a Record 5 should follow the Record 4. If multiple cuts are specified for a given time period (using a set of multiple Records 4) and regeneration is expected, only one Record 5 should be included at the end of the set of Records 4.

RECORD 4 – cut controls

NCPER	1–5	I5	Number of the growth period at which the cut is to occur. Cut occurs at the end of the growth period. Legal values are 0 (for an immediate cut) to the value of NGPERS from Record 1.
ICTYP	6–10	I5	Flag to specify type of cut. Values: 1 – uneven-aged 2 – thin from below 3 – thin from above 5 – remove species ICUTSP from below 6 – remove species ICUTSP from above Note ICTYP 5 and 6 remove only one species and override species retention priorities set on Record 2.
ICUTSP	11–13	I3	Standard inventory code for tree species to cut. Applies only to cut types (ICTYP) 5 or 6. Leave blank for other cut types.
IDENS	14–15	I2	Flag to specify the units of residual density goal, TGTDEN. Values: 1 – Trees per acre 2 – Basal area per acre 3 – Percent of current basal area For ICTYP equal to 1 (uneven-aged), IDENS must have a value of 2 (basal area).
TGTDEN	16–20	F5.0	Target density for the residual stand, expressed in units as specified by the value of IDENS. TGTDEN is the density goal between DMIN and DMAX.
DMIN	21–25	F5.0	Minimum d.b.h. class in which the cut is to occur. If left blank, default is 0 inches. For example, if a value of 5 is entered, the cut will occur in classes 5.0 inches and larger to the value of DMAX.
DMAX	26–30	F5.0	Maximum d.b.h. class in which the cut is to occur. If left blank, the default value is 99, implying the largest class in the stand. For example, if a value of 20 is entered, the cut will occur in trees from the value of DMIN up to 20.9 inches d.b.h.
QRATIO	31–35	F5.2	Q-ratio to specify diameter distribution goal for uneven-aged cuts. This is the ratio of number of trees in successive d.b.h. classes for 1-inch classes. The q-ratio for 1-inch classes is the square root of the q-ratio for 2-inch classes.
ICUTDM	36–37	I2	Flag to specify that cuts will consider dwarf mistletoe infection. A value of 0 specifies dwarf mistletoe will not be considered in the cut. Value of 1 specifies dwarf mistletoe will be reduced as much as possible. If left blank, default value is 0. Leave blank for stands without dwarf mistletoe.
IBURN	38	I1	Flag to specify if the cut will destroy all seedlings less than 4.5 feet tall (value of 1) or seedlings will not be affected (value of 0). If left blank, default is 0.
ICREGN	39	I1	Flag to specify if the cut will result in established regeneration (value of 1) or no regeneration is expected (value of 0). If left blank, default is 0. If no regeneration is expected, omit Record 5.
IDCUT	41–80	A40	40-character description of the cut. Leave blank for no description.

RECORD 5 – regeneration

IPERRG	1–5	I5	Number of the period during which regeneration is expected to become established. Legal values are NCPER (record 4) to NGPERS (record 1).
IDSPSD(1)	6–10	I5	Standard 3-digit species code for seedlings.
NSD(1)	11–15	I5	Number of established seedlings per acre.
SDHG(1)	16–20	F5.1	Expected 10-year periodic height growth to the nearest 0.1 foot for seedlings.

Repeat IDSPSD, NSD, and SDHG on Record 5 for as many species as are expected to regenerate for the forest type (up to five species).

Sample GENINP.CTL file

```
031000    1  80.  202      2                    DEMONSTRATION RUN – 2 DECADES
  5.0  4.0  9.0  6.0  1 2 3 4 5 6 7 8 910 1987
100.0
    0    1    2  80.    5.  24.  1.1 000  INITIAL UNEVEN-AGED CUT
    2    2    2  60.    0.  40.      000  THIN FROM BELOW TO 60 SQ. FT
```

Appendix 2

Format for Data Input File to GENGYM (GENINP.DAT)

Include a separate record for each 1-inch d.b.h. class of each species.

VARIABLE	COLUMNS	FORMAT	DESCRIPTION
IDENT	1–10	A10	Stand identification code. Compartment and stand number.
IDATE	11–14	I4	Date of inventory.
KSP	15–17	I3	Standard inventory code for tree species.
TREES	20–26	F7.1	Number of live trees per acre.
AVGDBH	27–30	F4.1	Average d.b.h. (inches) of live trees within d.b.h. class.
AVGHT	31–33	I3	Average total height (feet) of live trees within d.b.h. class.
AVGCRN	34	I1	Average crown ratio of live trees within d.b.h. class. Use Stage 2 inventory codes.
AVGDMR	35–37	F3.1	Average dwarf mistletoe rating.
AVEAGE	47–49	I3	Average age (years) at b.h. of live trees within d.b.h. class.
DIAGRO	50–52	F3.1	Average 10-year d.b.h. growth (inches) of live trees within d.b.h. class.
HGTGRO	53–56	F4.1	Average 5-year height growth (feet) of live trees within d.b.h. class.

Sample GENINP.DAT file

```
87130303278707015   180.0   .0  10 .0          15 .0   .2
87130303278707015    14.110.2 806 .0          90 .8
87130303278707015    10.012.1 727 .0          801.0
87130303278707202    56.4  5.1 356 .0          90 .2
87130303278707202    24.1  7.8 536 .0         120 .2
87130303278707202    32.2  9.5 635 .0         111 .7
87130303278707202    29.010.0 606 .0         100 .4
87130303278707202    23.011.3 725 .0         100 .6
87130303278707202    18.212.7 766 .0         115 .9
87130303278707202    18.615.4 816 .0         125 .7
87130303278707202     4.717.7 826 .0         110 .9
87130303278707202     3.520.4 787 .0         130 .4
87130303278707202     3.321.1 926 .0         1051.4
87130303278707202     3.022.1 914 .0         110 .9
87130303278707202     2.424.7 907 .0         120 .8
87130303278707202     4.525.6 875 .0         120 .8
87130303278707202     4.226.3 866 .0         125 .9
87130303278707202     1.927.9 846 .0         130 .6
87130303278707746    30.8  6.9 482 .0          80 .5
87130303278707746    23.5  7.9 541 .0          80 .2
87130303278707746    18.1  9.0 721 .0          80 .2
87130303278707746    12.310.9 732 .0          90 .4
```

Appendix 3

Output from Sample Input Files in Appendices 1 and 2

FILE GENOUT.DBH - 1-INCH-WIDE DIAMETER CLASSES

7-25-1990 9:56:12
SOUTHWESTERN MIXED CONIFER STANDS - PER ACRE BASIS - GROSS VOLUMES
REGION 3 FOREST 10 DISTRICT 0 SITE INDEX = 80. SPECIES 202
DEMONSTRATION RUN - 2 DECADES 8713030327

STAND CONDITIONS AT YEAR 1987

DBHCLASS	BA	TPA	DBH	HT	PCTCRN	AGE	DMR	TCF	MCF	BFS
(202)DOUGLAS-FIR										
5- 5.9	8.0	56.4	5.1	35.	55.	90.	.0	118.	47.	0.
7- 7.9	8.0	24.1	7.8	53.	55.	120.	.0	157.	129.	0.
9- 9.9	15.9	32.2	9.5	63.	45.	111.	.0	362.	323.	627.
10-10.9	15.8	29.0	10.0	60.	55.	100.	.0	344.	310.	697.
11-11.9	16.0	23.0	11.3	72.	45.	100.	.0	413.	383.	1120.
12-12.9	16.0	18.2	12.7	76.	55.	115.	.0	434.	409.	1418.
15-15.9	24.1	18.6	15.4	81.	55.	125.	.0	692.	661.	2759.
17-17.9	8.0	4.7	17.7	82.	55.	110.	.0	233.	224.	1019.
20-20.9	7.9	3.5	20.4	78.	65.	130.	.0	219.	211.	1020.
21-21.9	8.0	3.3	21.1	92.	55.	105.	.0	260.	252.	1234.
22-22.9	8.0	3.0	22.1	91.	35.	110.	.0	257.	248.	1236.
24-24.9	8.0	2.4	24.7	90.	65.	120.	.0	254.	245.	1258.
25-25.9	16.1	4.5	25.6	87.	45.	120.	.0	494.	477.	2468.
26-26.9	15.8	4.2	26.3	86.	55.	125.	.0	481.	465.	2416.
27-27.9	8.1	1.9	27.9	84.	55.	130.	.0	239.	231.	1214.
TOTL 1″+	183.7	229.0	12.1	61.	52.	107.	.0	4956.	4614.	18486.
(746)ASPEN										
6- 6.9	8.0	30.8	6.9	48.	15.	80.	.0	164.	132.	0.
7- 7.9	8.0	23.5	7.9	54.	5.	80.	.0	184.	159.	0.
9- 9.9	8.0	18.1	9.0	72.	5.	80.	.0	245.	222.	598.
10-10.9	8.0	12.3	10.9	73.	15.	90.	.0	247.	232.	895.
TOTL 1″+	32.0	84.7	8.3	58.	10.	81.	.0	839.	745.	1493.
(015)WHITE FIR										
S		180.0		1.			.0			
10-10.9	8.0	14.1	10.2	80.	55.	90.	.0	238.	218.	673.
12-12.9	8.0	10.0	12.1	72.	65.	80.	.0	213.	199.	749.
TOTL S+0	.0	180.0	.0	1.	50.	0.	.0	0.	0.	0.
TOTL 1″+	16.0	24.1	11.0	77.	59.	86.	.0	451.	417.	1422.
TOTL S+0	.0	180.0	.0	1.	50.	0.	.0	0.	0.	0.
TOTL 1″+	231.7	337.8	11.2	61.	42.	99.	.0	6247.	5776.	21401.

STAND CONDITIONS AT YEAR 1987
REMOVALS TYPE = UNEVEN-AGED CUT INITIAL UNEVEN-AGED CUT
RESIDUAL BASAL AREA = 80. MIN DBH CLASS = 5. MAX DBH CLASS = 24.
Q-RATIO = 1.10

DBHCLASS	BA	TPA	DBH	HT	PCTCRN	AGE	DMR	TCF	MCF	BFS
(202)DOUGLAS-FIR										
5- 5.9	6.5	45.8	5.1	35.	55.	90.	.0	96.	38.	0.
7- 7.9	3.0	9.0	7.8	53.	55.	120.	.0	59.	48.	0.
9- 9.9	12.8	26.0	9.5	63.	45.	111.	.0	292.	261.	506.
10-10.9	12.4	22.8	10.0	60.	55.	100.	.0	270.	243.	547.
11-11.9	12.3	17.7	11.3	72.	45.	100.	.0	318.	295.	861.
12-12.9	7.8	8.9	12.7	76.	55.	115.	.0	212.	199.	692.
15-15.9	10.3	8.0	15.4	81.	55.	125.	.0	296.	283.	1182.
24-24.9	.5	.1	24.7	90.	65.	120.	.0	15.	15.	76.
25-25.9	16.1	4.5	25.6	87.	45.	120.	.0	494.	477.	2468.
26-26.9	15.8	4.2	26.3	86.	55.	125.	.0	481.	465.	2416.
27-27.9	8.1	1.9	27.9	84.	55.	130.	.0	239.	231.	1214.
TOTL 1" +	105.6	148.9	11.4	58.	52.	104.	.0	2771.	2555.	9962.
(746)ASPEN										
6- 6.9	6.1	23.5	6.9	48.	15.	80.	.0	125.	100.	0.
7- 7.9	8.0	23.5	7.9	54.	5.	80.	.0	184.	159.	0.
9- 9.9	8.0	18.1	9.0	72.	5.	80.	.0	245.	222.	598.
10-10.9	8.0	12.3	10.9	73.	15.	90.	.0	247.	232.	895.
TOTL 1" +	30.1	77.4	8.4	59.	10.	82.	.0	800.	713.	1493.
(015)WHITE FIR										
10-10.9	8.0	14.1	10.2	80.	55.	90.	.0	238.	218.	673.
12-12.9	8.0	10.0	12.1	72.	65.	80.	.0	213.	199.	749.
TOTL 1" +	16.0	24.1	11.0	77.	59.	86.	.0	451.	417.	1422.
TOTL 1" +	151.7	250.3	10.5	60.	39.	95.	.0	4023.	3685.	12877.

STAND CONDITIONS AT YEAR 1987
RESIDUAL - AFTER CUT

DBHCLASS	BA	TPA	DBH	HT	PCTCRN	AGE	DMR	TCF	MCF	BFS
(202)DOUGLAS-FIR										
5- 5.9	1.5	10.6	5.1	35.	55.	90.	.0	22.	9.	0.
7- 7.9	5.0	15.1	7.8	53.	55.	120.	.0	98.	80.	0.
9- 9.9	3.1	6.2	9.5	63.	45.	111.	.0	70.	62.	121.
10-10.9	3.4	6.2	10.0	60.	55.	100.	.0	74.	67.	150.
11-11.9	3.7	5.3	11.3	72.	45.	100.	.0	96.	89.	259.
12-12.9	8.2	9.3	12.7	76.	55.	115.	.0	222.	209.	726.
15-15.9	13.8	10.6	15.4	81.	55.	125.	.0	395.	378.	1577.
17-17.9	8.0	4.7	17.7	82.	55.	110.	.0	233.	224.	1019.
20-20.9	7.9	3.5	20.4	78.	65.	130.	.0	219.	211.	1020.
21-21.9	8.0	3.3	21.1	92.	55.	105.	.0	260.	252.	1234.
22-22.9	8.0	3.0	22.1	91.	35.	110.	.0	257.	248.	1236.
24-24.9	7.5	2.3	24.7	90.	65.	120.	.0	238.	230.	1182.
TOTL 1" +	78.1	80.1	13.4	66.	54.	111.	.0	2185.	2059.	8524.
(746)ASPEN										
6- 6.9	1.9	7.3	6.9	48.	15.	80.	.0	39.	31.	0.
TOTL 1" +	1.9	7.3	6.9	48.	15.	80.	.0	39.	31.	0.
(015)WHITE FIR										
S		180.0		1.			.0			
TOTL S+0	.0	180.0	.0	1.	50.	0.	.0	0.	0.	0.
TOTL S+0	.0	180.0	.0	1.	50.	0.	.0	0.	0.	0.
TOTL 1" +	80.0	87.5	13.0	65.	50.	109.	.0	2224.	2090.	8524.

STAND CONDITIONS AT YEAR 1997

DBHCLASS	BA	TPA	DBH	HT	PCTCRN	AGE	DMR	TCF	MCF	BFS
(202)DOUGLAS-FIR										
5– 5.9	.9	4.7	5.8	39.	61.	100.	.0	13.	8.	0.
6– 6.9	1.2	5.7	6.3	41.	61.	100.	.0	20.	13.	0.
8– 8.9	4.0	9.7	8.7	57.	59.	130.	.0	83.	72.	0.
9– 9.9	2.5	5.4	9.2	59.	59.	130.	.0	54.	47.	82.
10–10.9	4.9	7.9	10.6	66.	51.	118.	.0	116.	107.	277.
11–11.9	3.3	4.8	11.3	66.	56.	111.	.0	80.	74.	216.
12–12.9	4.3	5.0	12.5	76.	48.	110.	.0	116.	109.	371.
13–13.9	5.9	5.8	13.7	79.	57.	125.	.0	168.	159.	600.
14–14.9	3.8	3.5	14.2	81.	57.	125.	.0	111.	105.	411.
16–16.9	14.1	9.4	16.6	84.	57.	135.	.0	421.	404.	1771.
17–17.9	1.9	1.2	17.1	86.	57.	135.	.0	57.	55.	246.
18–18.9	5.2	2.7	18.7	84.	57.	120.	.0	154.	149.	695.
19–19.9	4.0	2.0	19.2	86.	57.	120.	.0	121.	117.	553.
21–21.9	9.3	3.6	21.6	82.	64.	136.	.0	269.	260.	1283.
22–22.9	10.1	3.7	22.4	93.	54.	119.	.0	329.	318.	1591.
23–23.9	7.5	2.5	23.4	93.	36.	120.	.0	246.	239.	1207.
25–25.9	4.7	1.3	25.7	91.	66.	130.	.0	153.	148.	767.
26–26.9	3.5	.9	26.2	92.	66.	130.	.0	114.	111.	574.
TOTL 1″ +	91.1	79.9	14.5	70.	56.	121.	.0	2626.	2493.	10642.
(746)ASPEN										
7– 7.9	1.8	5.7	7.6	52.	21.	90.	.0	39.	33.	0.
8– 8.9	.4	1.2	8.1	54.	21.	90.	.0	10.	8.	0.
TOTL 1″ +	2.2	6.9	7.7	52.	21.	90.	.0	49.	42.	0.
(015)WHITE FIR										
S		122.5		1.			.0			
0– 0.9	.1	44.8	.5	6.	100.	5.	.0	0.	0.	0.
TOTL S+0	.1	167.3	.3	3.	63.	1.	.0	0.	0.	0.
TOTL S+0	.1	167.3	.3	3.	63.	1.	.0	0.	0.	0.
TOTL 1″ +	93.3	86.8	14.0	69.	54.	119.	.0	2675.	2535.	10642.

STAND CONDITIONS AT YEAR 2007

DBHCLASS	BA	TPA	DBH	HT	PCTCRN	AGE	DMR	TCF	MCF	BFS
(202)DOUGLAS-FIR										
6– 6.9	1.2	5.1	6.7	43.	65.	110.	.0	21.	15.	0.
7– 7.9	1.5	5.1	7.3	46.	65.	110.	.0	26.	20.	0.
9– 9.9	4.5	8.9	9.7	61.	62.	140.	.0	100.	90.	183.
10–10.9	3.5	6.2	10.3	64.	62.	140.	.0	82.	74.	179.
11–11.9	4.8	6.5	11.6	70.	55.	127.	.0	120.	112.	344.
12–12.9	5.2	6.2	12.4	71.	57.	123.	.0	131.	123.	411.
13–13.9	4.5	4.5	13.6	80.	51.	120.	.0	129.	122.	456.
14–14.9	5.8	4.9	14.6	82.	58.	133.	.0	169.	161.	645.
15–15.9	6.3	4.9	15.3	84.	59.	135.	.0	187.	179.	745.
17–17.9	12.8	7.5	17.6	87.	58.	145.	.0	393.	378.	1718.
18–18.9	5.6	3.1	18.2	88.	58.	145.	.0	175.	168.	776.
19–19.9	3.9	1.8	19.7	87.	58.	130.	.0	120.	116.	553.
20–20.9	6.4	2.9	20.4	88.	58.	130.	.0	200.	193.	936.
22–22.9	7.2	2.6	22.6	84.	65.	146.	.0	213.	205.	1029.
23–23.9	12.8	4.3	23.5	92.	58.	133.	.0	416.	403.	2039.
24–24.9	8.9	2.7	24.5	95.	41.	130.	.0	297.	288.	1473.
25–25.9	.9	.3	25.1	96.	38.	130.	.0	30.	29.	149.
26–26.9	3.7	1.0	26.7	93.	66.	140.	.0	121.	118.	613.
27–27.9	5.3	1.3	27.3	94.	66.	140.	.0	175.	170.	889.
TOTL 1″ +	104.8	79.7	15.5	74.	59.	131.	.0	3106.	2964.	13140.
(746)ASPEN										
7– 7.9	.3	.8	7.9	54.	26.	100.	.0	6.	5.	0.
8– 8.9	2.1	5.3	8.5	56.	26.	100.	.0	49.	43.	0.
9– 9.9	.2	.4	9.2	58.	26.	100.	.0	5.	4.	12.
TOTL 1″ +	2.5	6.5	8.4	55.	26.	100.	.0	59.	53.	12.

(015)WHITE FIR										
S		84.4		2.			.0			
0– 0.9	.1	39.0	.6	7.	100.	8.	.0	0.	0.	0.
1– 1.9	.3	31.1	1.4	9.	100.	15.	.0	6.	0.	0.
TOTL S+0	.1	123.4	.3	3.	66.	2.	.0	0.	0.	0.
TOTL 1″+	.3	31.1	1.4	9.	100.	15.	.0	6.	0.	0.
TOTL S+0	.1	123.4	.3	3.	66.	2.	.0	0.	0.	0.
TOTL 1″+	107.6	117.3	13.0	56.	68.	99.	.0	3171.	3017.	13151.

STAND CONDITIONS AT YEAR 2007
REMOVALS TYPE = CUT FROM BELOW THIN FROM BELOW TO 60 SQ. FT.
RESIDUAL BASAL AREA = 60. MIN DBH CLASS = 0. MAX DBH CLASS = 40.

DBHCLASS	BA	TPA	DBH	HT	PCTCRN	AGE	DMR	TCF	MCF	BFS
(202)DOUGLAS-FIR										
6– 6.9	1.2	5.1	6.7	43.	65.	110.	.0	21.	15.	0.
7– 7.9	1.5	5.1	7.3	46.	65.	110.	.0	26.	20.	0.
9– 9.9	4.5	8.9	9.7	61.	62.	140.	.0	100.	90.	183.
10–10.9	3.5	6.2	10.3	64.	62.	140.	.0	82.	74.	179.
11–11.9	4.8	6.5	11.6	70.	55.	127.	.0	120.	112.	344.
12–12.9	5.2	6.2	12.4	71.	57.	123.	.0	131.	123.	411.
13–13.9	4.5	4.5	13.6	80.	51.	120.	.0	129.	122.	456.
14–14.9	5.8	4.9	14.6	82.	58.	133.	.0	169.	161.	645.
15–15.9	6.3	4.9	15.3	84.	59.	135.	.0	187.	179.	745.
17–17.9	7.5	4.4	17.6	87.	58.	145.	.0	230.	221.	1003.
TOTL 1″+	44.8	56.7	12.0	68.	59.	129.	.0	1195.	1117.	3966.
(746)ASPEN										
7– 7.9	.3	.8	7.9	54.	26.	100.	.0	6.	5.	0.
8– 8.9	2.1	5.3	8.5	56.	26.	100.	.0	49.	43.	0.
9– 9.9	.2	.4	9.2	58.	26.	100.	.0	5.	4.	12.
TOTL 1″+	2.5	6.5	8.4	55.	26.	100.	.0	59.	53.	12.
(015)WHITE FIR										
0– 0.9	.1	39.0	.6	7.	100.	8.	.0	0.	0.	0.
1– 1.9	.3	31.1	1.4	9.	100.	15.	.0	6.	0.	0.
TOTL S+0	.1	39.0	.6	7.	100.	8.	.0	0.	0.	0.
TOTL 1″+	.3	31.1	1.4	9.	100.	15.	.0	6.	0.	0.
TOTL S+0	.1	39.0	.6	7.	100.	8.	.0	0.	0.	0.
TOTL 1″+	47.6	94.3	9.6	48.	70.	90.	.0	1260.	1170.	3978.

STAND CONDITIONS AT YEAR 2007
RESIDUAL – AFTER CUT

DBHCLASS	BA	TPA	DBH	HT	PCTCRN	AGE	DMR	TCF	MCF	BFS
(202)DOUGLAS-FIR										
17–17.9	5.3	3.1	17.6	87.	58.	145.	.0	164.	157.	714.
18–18.9	5.6	3.1	18.2	88.	58.	145.	.0	175.	168.	776.
19–19.9	3.9	1.8	19.7	87.	58.	130.	.0	120.	116.	553.
20–20.9	6.4	2.9	20.4	88.	58.	130.	.0	200.	193.	936.
22–22.9	7.2	2.6	22.6	84.	65.	146.	.0	213.	205.	1029.
23–23.9	12.8	4.3	23.5	92.	58.	133.	.0	416.	403.	2039.
24–24.9	8.9	2.7	24.5	95.	41.	130.	.0	297.	288.	1473.
25–25.9	.9	.3	25.1	96.	38.	130.	.0	30.	29.	149.
26–26.9	3.7	1.0	26.7	93.	66.	140.	.0	121.	118.	613.
27–27.9	5.3	1.3	27.3	94.	66.	140.	.0	175.	170.	889.
TOTL 1″+	60.0	23.0	21.9	90.	57.	137.	.0	1911.	1847.	9173.
(015)WHITE FIR										
S		84.4		2.			.0			
TOTL S+0	.0	84.4	.0	2.	50.	0.	.0	0.	0.	0.
TOTL S+0	.0	84.4	.0	2.	50.	0.	.0	0.	0.	0.
TOTL 1″+	60.0	23.0	21.9	90.	57.	137.	.0	1911.	1847.	9173.

TOTAL VOLUMES REMOVED BY CUTTING	5283.	4855.	16855.

FILE GENOUT.SPP - SUMMARY BY SPECIES

7-25-1990 9:56:12
SOUTHWESTERN MIXED CONIFER STANDS - PER ACRE BASIS - GROSS VOLUMES
REGION 3 FOREST 10 DISTRICT 0 SITE INDEX = 80. SPECIES 202
DEMONSTRATION RUN - 2 DECADES 8713030327

	BA	TPA	DBH	HT	PCTCRN	AGE	DMR	TCF	MCF	BFS
STAND CONDITIONS AT YEAR 1987										
(202)DOUGLAS-FIR										
TOTL 1″+	183.7	229.0	12.1	61.	52.	107.	.0	4956.	4614.	18486.
(746)ASPEN										
TOTL 1″+	32.0	84.7	8.3	58.	10.	81.	.0	839.	745.	1493.
(015)WHITE FIR										
TOTL S+0	.0	180.0	.0	1.	50.	0.	.0	0.	0.	0.
TOTL 1″+	16.0	24.1	11.0	77.	59.	86.	.0	451.	417.	1422.
TOTL S+0	.0	180.0	.0	1.	50.	0.	.0	0.	0.	0.
TOTL 1″+	231.7	337.8	11.2	61.	42.	99.	.0	6247.	5776.	21401.
STAND CONDITIONS AT YEAR 1987										
REMOVALS TYPE = UNEVEN-AGED CUT INITIAL UNEVEN-AGED CUT										
(202)DOUGLAS-FIR										
TOTL 1″+	105.6	148.9	11.4	58.	52.	104.	.0	2771.	2555.	9962.
(746)ASPEN										
TOTL 1″+	30.1	77.4	8.4	59.	10.	82.	.0	800.	713.	1493.
(015)WHITE FIR										
TOTL 1″+	16.0	24.1	11.0	77.	59.	86.	.0	451.	417.	1422.
TOTL 1″+	151.7	250.3	10.5	60.	39.	95.	.0	4023.	3685.	12877.
STAND CONDITIONS AT YEAR 1987										
RESIDUAL - AFTER CUT										
(202)DOUGLAS-FIR										
TOTL 1″+	78.1	80.1	13.4	66.	54.	111.	.0	2185.	2059.	8524.
(746)ASPEN										
TOTL 1″+	1.9	7.3	6.9	48.	15.	80.	.0	39.	31.	0.
(015)WHITE FIR										
TOTL S+0	.0	180.0	.0	1.	50.	0.	.0	0.	0.	0.
TOTL S+0	.0	180.0	.0	1.	50.	0.	.0	0.	0.	0.
TOTL 1″+	80.0	87.5	13.0	65.	50.	109.	.0	2224.	2090.	8524.
STAND CONDITIONS AT YEAR 1997										
(202)DOUGLAS-FIR										
TOTL 1″+	91.1	79.9	14.5	70.	56.	121.	.0	2626.	2493.	10642.
(746)ASPEN										
TOTL 1″+	2.2	6.9	7.7	52.	21.	90.	.0	49.	42.	0.
(015)WHITE FIR										
TOTL S+0	.1	167.3	.3	3.	63.	1.	.0	0.	0.	0.
TOTL S+0	.1	167.3	.3	3.	63.	1.	.0	0.	0.	0.
TOTL 1″+	93.3	86.8	14.0	69.	54.	119.	.0	2675.	2535.	10642.

STAND CONDITIONS AT YEAR 2007

(202)DOUGLAS-FIR										
TOTL 1″ +	104.8	79.7	15.5	74.	59.	131.	.0	3106.	2964.	13140.
(746)ASPEN										
TOTL 1″ +	2.5	6.5	8.4	55.	26.	100.	.0	59.	53.	12.
(015)WHITE FIR										
TOTL S+0	.1	123.4	.3	3.	66.	2.	.0	0.	0.	0.
TOTL 1″ +	.3	31.1	1.4	9.	100.	15.	.0	6.	0.	0.
TOTL S+0	.1	123.4	.3	3.	66.	2.	.0	0.	0.	0.
TOTL 1″ +	107.6	117.3	13.0	56.	68.	99.	.0	3171.	3017.	13151.

STAND CONDITIONS AT YEAR 2007
REMOVALS TYPE = CUT FROM BELOW THIN FROM BELOW TO 60 SQ. FT.

(202)DOUGLAS-FIR										
TOTL 1″ +	44.8	56.7	12.0	68.	59.	129.	.0	1195.	1117.	3966.
(746)ASPEN										
TOTL 1″ +	2.5	6.5	8.4	55.	26.	100.	.0	59.	53.	12.
(015)WHITE FIR										
TOTL S+0	.1	39.0	.6	7.	100.	8.	.0	0.	0.	0.
TOTL 1″ +	.3	31.1	1.4	9.	100.	15.	.0	6.	0.	0.
TOTL S+0	.1	39.0	.6	7.	100.	8.	.0	0.	0.	0.
TOTL 1″ +	47.6	94.3	9.6	48.	70.	90.	.0	1260.	1170.	3978.

STAND CONDITIONS AT YEAR 2007
RESIDUAL – AFTER CUT

(202)DOUGLAS-FIR										
TOTL 1″ +	60.0	23.0	21.9	90.	57.	137.	.0	1911.	1847.	9173.
(015)WHITE FIR										
TOTL S+0	.0	84.4	.0	2.	50.	0.	.0	0.	0.	0.
TOTL S+0	.0	84.4	.0	2.	50.	0.	.0	0.	0.	0.
TOTL 1″ +	60.0	23.0	21.9	90.	57.	137.	.0	1911.	1847.	9173.

TOTAL VOLUMES REMOVED BY CUTTING	5283.	4855.	16855.

FILE GENOUT.STD – WHOLE STAND SUMMARY

7–25–1990 9:56:12
SOUTHWESTERN MIXED CONIFER STANDS – PER ACRE BASIS – GROSS VOLUMES
REGION 3 FOREST 10 DISTRICT 0 SITE INDEX = 80. SPECIES 202
DEMONSTRATION RUN – 2 DECADES 8713030327

	BA	TPA	DBH	HT	PCTCRN	AGE	DMR	TCF	MCF	BFS
STAND CONDITIONS AT YEAR 1987										
TOTL S+0	.0	180.0	.0	1.	50.	0.	.0	0.	0.	0.
TOTL 1″+	231.7	337.8	11.2	61.	42.	99.	.0	6247.	5776.	21401.
REMOVALS TYPE = UNEVEN-AGED CUT INITIAL UNEVEN-AGED CUT										
TOTL 1″+	151.7	250.3	10.5	60.	39.	95.	.0	4023.	3685.	12877.
RESIDUAL – AFTER CUT										
TOTL S+0	.0	180.0	.0	1.	50.	0.	.0	0.	0.	0.
TOTL 1″+	80.0	87.5	13.0	65.	50.	109.	.0	2224.	2090.	8524.
STAND CONDITIONS AT YEAR 1997										
TOTL S+0	.1	167.3	.3	3.	63.	1.	.0	0.	0.	0.
TOTL 1″+	93.3	86.8	14.0	69.	54.	119.	.0	2675.	2535.	10642.
STAND CONDITIONS AT YEAR 2007										
TOTL S+0	.1	123.4	.3	3.	66.	2.	.0	0.	0.	0.
TOTL 1″+	107.6	117.3	13.0	56.	68.	99.	.0	3171.	3017.	13151.
REMOVALS TYPE = CUT FROM BELOW THIN FROM BELOW TO 60 SQ. FT.										
TOTL S+0	.1	39.0	.6	7.	100.	8.	.0	0.	0.	0.
TOTL 1″+	47.6	94.3	9.6	48.	70.	90.	.0	1260.	1170.	3978.
RESIDUAL – AFTER CUT										
TOTL S+0	.0	84.4	.0	2.	50.	0.	.0	0.	0.	0.
TOTL 1″+	60.0	23.0	21.9	90.	57.	137.	.0	1911.	1847.	9173.
TOTAL VOLUMES REMOVED BY CUTTING								5283.	4855.	16855.

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FILE GENOUT.DAT - OUTPUT IN DIAMETER CLASS INPUT FORMAT
    7-25-1990        9:56:12
  STAND CONDITIONS AT YEAR 1987
8713030327          202          56.4  5.1  356  .0            90
8713030327          202          24.1  7.8  535  .0           120
8713030327          202          32.2  9.5  635  .0           111
8713030327          202          29.010.0  606  .0            100
8713030327          202          23.011.3  725  .0            100
8713030327          202          18.212.7  765  .0            115
8713030327          202          18.615.4  815  .0            125
8713030327          202           4.717.7  826  .0            110
8713030327          202           3.520.4  787  .0            130
8713030327          202           3.321.1  926  .0            105
8713030327          202           3.022.1  914  .0            110
8713030327          202           2.424.7  907  .0            120
8713030327          202           4.525.6  875  .0            120
8713030327          202           4.226.3  865  .0            125
8713030327          202           1.927.9  846  .0            130
8713030327          746          30.8  6.9  481  .0            80
8713030327          746          23.5  7.9  541  .0            80
8713030327          746          18.1  9.0  721  .0            80
8713030327          746          12.310.9  731  .0             90
8713030327          015         180.0        1  .0                      .4
8713030327          015          14.110.2  806  .0             90
8713030327          015          10.012.1  726  .0             80
  STAND CONDITIONS AT YEAR 1987
  RESIDUAL - AFTER CUT
8713030327          202          10.6  5.1  356  .0            90
8713030327          202          15.1  7.8  535  .0           120
8713030327          202           6.2  9.5  635  .0           111
8713030327          202           6.210.0  606  .0            100
8713030327          202           5.311.3  725  .0            100
8713030327          202           9.312.7  765  .0            115
8713030327          202          10.615.4  815  .0            125
8713030327          202           4.717.7  826  .0            110
8713030327          202           3.520.4  787  .0            130
8713030327          202           3.321.1  926  .0            105
8713030327          202           3.022.1  914  .0            110
8713030327          202           2.324.7  907  .0            120
8713030327          746           7.3  6.9  481  .0            80
8713030327          015         180.0        1  .0                      .4
  STAND CONDITIONS AT YEAR 1997
8713030327          202           4.7  5.8  396  .0           100
8713030327          202           5.7  6.3  416  .0           100
8713030327          202           9.7  8.7  576  .0           130
8713030327          202           5.4  9.2  596  .0           130
8713030327          202           7.910.6  665  .0            118
8713030327          202           4.811.3  666  .0            111
8713030327          202           5.012.5  765  .0            110
8713030327          202           5.813.7  796  .0            125
8713030327          202           3.514.2  816  .0            125
8713030327          202           9.416.6  846  .0            135
8713030327          202           1.217.1  866  .0            135
8713030327          202           2.718.7  846  .0            120
8713030327          202           2.019.2  866  .0            120
8713030327          202           3.621.6  826  .0            136
8713030327          202           3.722.4  935  .0            119
8713030327          202           2.523.4  934  .0            120
8713030327          202           1.325.7  917  .0            130
8713030327          202            .926.2  927  .0            130
8713030327          746           5.7  7.6  522  .0            90
8713030327          746           1.2  8.1  542  .0            90
8713030327          015         122.5        1  .0                      .4
8713030327          015          44.8   .5   69  .0             5
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STAND CONDITIONS AT YEAR 2007

8713030327	202	5.1 6.7	436	.0	110	
8713030327	202	5.1 7.3	466	.0	110	
8713030327	202	8.9 9.7	616	.0	140	
8713030327	202	6.210.3	646	.0	140	
8713030327	202	6.511.6	705	.0	127	
8713030327	202	6.212.4	716	.0	123	
8713030327	202	4.513.6	805	.0	120	
8713030327	202	4.914.6	826	.0	133	
8713030327	202	4.915.3	846	.0	135	
8713030327	202	7.517.6	876	.0	145	
8713030327	202	3.118.2	886	.0	145	
8713030327	202	1.819.7	876	.0	130	
8713030327	202	2.920.4	886	.0	130	
8713030327	202	2.622.6	847	.0	146	
8713030327	202	4.323.5	926	.0	133	
8713030327	202	2.724.5	954	.0	130	
8713030327	202	.325.1	964	.0	130	
8713030327	202	1.026.7	937	.0	140	
8713030327	202	1.327.3	947	.0	140	
8713030327	746	.8 7.9	543	.0	100	
8713030327	746	5.3 8.5	563	.0	100	
8713030327	746	.4 9.2	583	.0	100	
8713030327	015	84.4	2	.0		.4
8713030327	015	39.0 .6	79	.0	8	
8713030327	015	31.1 1.4	99	.0	15	

STAND CONDITIONS AT YEAR 2007
RESIDUAL – AFTER CUT

8713030327	202	3.117.6	876	.0	145	
8713030327	202	3.118.2	886	.0	145	
8713030327	202	1.819.7	876	.0	130	
8713030327	202	2.920.4	886	.0	130	
8713030327	202	2.622.6	847	.0	146	
8713030327	202	4.323.5	926	.0	133	
8713030327	202	2.724.5	954	.0	130	
8713030327	202	.325.1	964	.0	130	
8713030327	202	1.026.7	937	.0	140	
8713030327	202	1.327.3	947	.0	140	
8713030327	015	84.4	2	.0		.4

Edminster, Carleton B.; Mowrer, H. Todd; Mathiasen, Robert L.; Schuler, Thomas M.; Olsen, William K.; Hawksworth, Frank G. 1990. GENGYM: a variable density stand table projection system calibrated for mixed conifer and ponderosa pine stands in the Southwest. Res. Pap. RM-297. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 32 p.

A computerized growth and yield model based on a variable density stand table projection system using 1-inch-wide diameter classes has been developed for projecting expected stand conditions in southwestern mixed conifer and ponderosa pine stands, including the effects of dwarf mistletoe. Stand management options include both even-aged and uneven-aged cutting methods.

Keywords: Stand growth, yield, even-aged management, uneven-aged management, *Pseudotsuga menziesii*, *Pinus ponderosa*, *Abies concolor*

U.S. Department of Agriculture
Forest Service

Rocky Mountain Forest and Range Experiment Station

Rocky Mountains

Southwest

Great Plains

The Rocky Mountain Station is one of eight regional experiment stations, plus the Forest Products Laboratory and the Washington Office Staff, that make up the Forest Service research organization.

RESEARCH FOCUS

Research programs at the Rocky Mountain Station are coordinated with area universities and with other institutions. Many studies are conducted on a cooperative basis to accelerate solutions to problems involving range, water, wildlife and fish habitat, human and community development, timber, recreation, protection, and multiresource evaluation.

RESEARCH LOCATIONS

Research Work Units of the Rocky Mountain Station are operated in cooperation with universities in the following cities:

Albuquerque, New Mexico
Flagstaff, Arizona
Fort Collins, Colorado*
Laramie, Wyoming
Lincoln, Nebraska
Rapid City, South Dakota
Tempe, Arizona

*Station Headquarters: 240 W. Prospect Rd., Fort Collins, CO 80526